CANADA - ONTARIO AGREEMENT

PUBLICATIONS

Relating to

SEWAGE SLUDGE PRODUCTION, TREATMENT, HANDLING, UTILIZATION AND DISPOSAL

May, 1979

Ministry
of the
Environment

Ontario

CANADA ONTARIO AGREEMENT

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Relating to

SEWAGE SLUDGE PRODUCTION, TREATMENT, HANDLING, UTILIZATION AND DISPOSAL

MUNICIPAL AND PRIVATE ABATEMENT SECTION

POLLUTION CONTROL BRANCH

ONTARIO MINISTRY OF THE ENVIRONMENT

MAY, 1979

FOREWORD

This report will be of interest to persons who wish to study the research which was used as a basis for the Ontario Ministry of the Environment's April 1978 publication: "Guidelines for Sewage Sludge Utilization on Agricultural Lands". It lists and includes abstracts of Canada-Ontario Agreement research publications on sewage sludge production, treatment, handling and disposal.

CANADA-ONTARIO AGREEMENT RESEARCH REPORT SUMMARIES

ON SEWAGE SLUDGE

These summaries describe research projects funded under the Research Program for the Abatement of Municipal Pollution within the provisions of the Canada/Ontario Agreement on Great Lakes Water Quality. They provide information on the studies carried out in this program through in-house projects by both Environment Canada and the Ontario Ministry of the Environment, and through contracts with municipalities, research institutions and industrial organizations.

More comprehensive and detailed RESEARCH REPORTS on the projects covered by these summaries have been submitted by the contractors. Requests for copies of Canada/Ontario Agreement Research Reports should be directed to:

Training and Technology Transfer
Division (Water),
Environmental Protection Service,
Environment Canada,
Ottawa, Ontario
KlA 0H3

Enquiries concerning the Canada-Ontario Agreement RESEARCH PROGRAM should be directed to:

Ontario Ministry of the Environment,
Pollution Control Branch,
135 St. Clair Avenue West,
Toronto, Ontario
M4V 1P5

Wastewater Technology Centre,
Canada Centre for Inland Waters,
Environment Canada,
P.O. Box 5050,
Burlington, Ontario
L7R 4A6

A List of available summaries is provided on the next page. These provide a guide to location of the summaries in subsequent pages.

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CONFERENCE PROCEEDINGS NO. 2

SLUDGE HANDLING AND DISPOSAL SEMINAR

September 18-19, 1974

Toronto, Ontario

The disposal of sewage sludge onto agricultural lands under proper conditions is not only economical but can result in fertilization and improvement of soil properties. Recently, however, questions have arisen concerning the potential environmental problems associated with this method of disposal and the introduction of chemical sludges from phosphorus removal facilities has further complicated these questions. Studies are needed to fully understand and determine the nitrogen balance, and movement and fate of nitrogen compounds in soils, plants and water. The level of heavy metals in sludges is also of concern because of potential problems associated with build-up in soil, uptake by plants, effect on plant growth, runoff, pollution of groundwater and leaching after long-term build-up in soil. In addition, very little is known about the pathogenic aspects of sewage sludge disposal on land.

The sludge handling topics discussed at this seminar covered such subjects as: dewatering, filtration, centrifugation, incineration, metal removal or reclamation, trucking and pumping. Results of research projects funded under the Canada-Ontario Agreement on both sludge handling and disposal were discussed by approximately thirty authors and researchers.

Compilation of papers: 28

Total of 465 pages, illustrations, tables

LIST OF PAPERS PRESENTED

SLUDGE UTILIZATION AND DISPOSAL SEMINAR
February 20-21, 1978

The Utilization of sewage sludge is carefully distinguished from the various methods of ultimate disposal. Problems, practices and trends arising in sludge utilization on agricultural land, including viruses parasites and heavy metals are reviewed. Sludge treatment options for disposal are presented and their costs are discussed.

Ontario's proposed guidelines for sewage sludge utilization on agricultural lands and procedures for obtaining approval for such applications are presented.

Compilation of Papers: 28

Total of illustrations, tables, papers: 471 p.

LIST OF PAPERS

RESEARCH REPORT NO. 1

LAND APPLICATION OF SEWAGE SLUDGE

UNIVERSITY OF GUELPH

This is a literature review undertaken largely to determine the extent of present knowledge for ecologically safe and agriculturally productive application of sewage sludges to farm lands.

From this review it was concluded that sludge is quite variable in solids and nutrient content from one sewage plant to another and from day to day and/or week to week at any one plant. This is foreseen as a possible major problem in establishing safe rates of application.

Nitrogen is likely to control rates of sludge application which should be restricted to those needed for crop production, at least until more information is availbale. Leaching of phosphorus into the groundwater is not expected to be a major problem controlling application rates, except on organic and sandy soils. Phosphorus could cause problems in surface drainage due to erosion and runoff.

The metals copper, zinc, cadmium, nickel, chromium and lead are high in some sludges and may be cause for concern. Other metals may also be of concern in particular sludges. Toxicities of copper and zinc to plants have caused problems in Britain and Europe. Cadmium is of concern for human health reasons. Since this review was written, it has also been reported to reduce plant growth at tissue levels as low as two parts per million. Soils absorb large quantities of most metals in forms unavailable to plants, provided there is a plentiful oxygen supply and the soil pH is maintained at a high level. It is suggested, however, that the best long-term method of controlling heavy metals may be to prevent them from reaching the sewage plant.

Studies are reported on the survival of human and animal pathogens and viruses in sludge. The populations are reduced but not eliminated by anaerobic digestion. They are essentially eliminated by heat drying. Human and animal parasites, particularly ascaris, survive sludge digestion and may persist in and on the soil for considerable periods. Survival time increases with high clay and organic matter content in soils.

No information was found concerning the land application of sludges resulting from treating sewage with chemicals for the removal of nutrients. Although major problems are not expected with these sludges resulting from the use of lime, aluminum sulphate and ferric chloride, research is needed.

Little information was found on times and methods of sludge applications which will prevent or eliminate water contamination by erosion and renoff.

Author: T.E. Bates, Department of Land Resource Science,
University of Guelph, Guelph, Ontario

Project No. 71-4-1
212 p., table, references are listed in call number, alphabetical by author, and principal key word order.

RESEARCH REPORT NO. 3

AEROBIC DIGESTION OF ORGANIC SLUDGES CONTAINING INORGANIC POHSPHORUS PRECIPITATES

PHASE 1

University of Toronto

Biological stabilization of organic sludges can be accomplished using either anaerobic or aerobic digestion. The use of aerobic digestion is becoming popular for small wastewater treatment plants as operating problems and costs are significantly reduced. Although considerable research has already been conducted on the aerobic digestion process, insufficient information is available for a rational design of treatment units. This situation is further complicated by the use of various chemicals for phosphorus precipitation as the characteristics and treatability of sludges produced may be affected by chemical addition.

The general objective of this research project was to establish:

a) feasibility of treatment of organic sludges containing inorganic phosphorus precipitates by the aerobic digestion process;
b) performance data that could be used in the formulation of a rational basis for the design of aerobic digesters;and
c) concentrations of nutrients and dissolved organics released during aerobic digestion.

The study consisted of three series of laboratory batch and semi-continuous experiments carried out at 20°C on the aerobic digestion of activated sludges containing aluminum salts (precipitation with alum) or ferric salts (precipitation with ferric chloride) used for phosphorus precipitation. Treatment responses measured were digested sludge characteristics (volatile solids destruction, oxygen uptake, settleability and dewaterability) and supernatant characteristics (soluble total organic carbon, soluble nutrients and suspended solids). The only variable that was controlled for all experiments was the sludge hydraulic detention time.

Series I of the experiments consisted of 3 batch aeration tests which lasted 28 days and were carried out using sludges precipitated with alum (200 mg/l) or ferric chloride (10 mg/l as Fe+++) and a control sludge. Series II covered 3 batch aeration tests that lasted for 21 days to treat sludges precipitated with alum (550 mg/l) of ferric chloride (30 mg/l as Fe+++) and a control sludge. In Series III, aerobic digestion of the above 4 types of chemical sludges as well as a control sludge was carried out in both batch units (10 day aeration) and semi-continuous units (10 day theoretical detention time). The semi-continuous units were operated at average loadings of 0.06 lb Vs/day/cu ft (960 g Vs/day/cu m). All experiments were carried out using initial suspended solids concentrations in the range, 9,000 to 14,000 mg/l.

The aerobic digestion of conventional activated sludge was not affected to any significant degree by the presence of ferric or aluminum precipitates. For both the control and chemically precipitated sludges an aeration period of 10 to 15 days was required for stabilization. Release of soluble organic carbon and nutrients during the aerobic digestion of activated sludges was not altered appreciably in the presence of the chemical precipitates. At the higher chemical dosages there was a reduction in nutrient release in the supernatant. Dewaterability and settling characteristics of control and chemically precipitated digested sludges did not differ significantly.

Principal Author: J. Ganczarzk, Dept. of Civil Engineering, Institute of Environmental Sciences and Engineering, University of Toronto, Toronto, Ontario.

Project No. 72-5-4

71 p., figures, tables, bibliography

RESEARCH REPORT NO. 9

HEAVY METALS IN AGRICULTURAL LANDS RECEIVING

CHEMICAL SEWAGE SLUDGES

University of Toronto

The disposal of sewage treatment plant sludges poses a serious problem. Potentially, these materials could be used as fertilizers on agricultural lands. This would be a double benefit acting as a disposal mechanism as well as a source of plant nutrients. On the other hand, a variety of reports have appeared urging caution in this regard for fear of contamination of the land by other matrix constituents. Among these are the potentially toxic heavy metals.

A series of reports, most of which have appeared in the past year, describe the metal content of domestic sewage plant sludges and sewage sludge fertilizers. A selection of references is given at the end of this report.

Researchers in several countries are presently developing projects designed to study the uptake by plants of heavy metals from sludged or otherwise metal contaminated soils. References on this subject also appear at the end of this report.

Despite a good deal of activity in this subject area, it is clear, from the references available to date, that very little data exist which reliably describe plant-metal interactions. Perhaps the most serious omission is that little attempt has been made in these papers to provide data on precision and accuracy of results.

In this project sludge characterization studies were conducted on samples obtained from North Toronto, Newmarket and Point Edward sewage treatment plants. Metal analyses were performed on Newmarket soils and vegetation on two farms which had received applications of sludge in 1971 and 1972. Metal analyses were also carried out on run-off water samples obtained in and around the sludge disposal area at the North Toronto sewage treatment plant.

The emphasis in this study was placed on the use of standard and control samples as tools for validating the data obtained. Because of the shortness of the investigation period, however, no attempt was made to use statistical testing to provide a means for arriving at conclusions. It would seem too early to justify anything but a few generalizations.

Appendix I of this report lists additional references not cited in the text which may be of use to interested readers.

A second appendix presents data obtained from vegetation studies conducted during the 1973-74 contract period. A final report containing more detailed information will be completed at the end of 1974.

Author: J.C. Van Loon, Associate Professor, Departments of Geology, Chemistry and the Institute of Environmental Sciences and Engineering, University of Toronto, Toronto, Ontario.

Project No. 72-5-3

37 p., figures, tables.

RESEARCH REPORT NO. 12

WET AIR OXIDATION OF CHEMICAL SLUDGES

University of Waterloo

The objectives of this contract were to evaluate on a laboratory scale the Wet Air Oxidation (WAO) or Zimmermann process for the destructive oxidation of mixed chemical-biological sludges, produced by chemical precipitation of nutrients and other components in several conventional waste treatment plants in Ontario. The fate of phosphorus during oxidation was to be investigated to assess its stabilization in the sludges.

This report describes a study of the wet air oxidation of eight Ontario sludges containing phosphorus. Sludges were obtained from the Canada Centre for Inland Waters, Burlington, Ontario. All came from municipal sources and comprised primary and secondary sludges, as well as chemical sludges, that is, sludges recovered where chemicals had been added. The latter group consisted of sludges obtained where alum, ferric chloride and lime were used to remove soluble phosphorus from municipal wastewaters.

Sludges were oxidized at temperatures up to 550°F (288°C) in a rocking bomb autoclave designed for this purpose, while carbon and total organic carbon values were measured in samples withdrawn during oxidation. Selected total phosphorus and orthophosphorus analyses were made on both chemical and non-chemical sludges.

For most sludges at 500°F, a reduction of at least 50% of the TOC was produced by three hours exposure to wet air oxidation. However, high batch-to-batch variation was observed in replicate runs. Mass transfer limitations appeared to be present except in the case of the activated sludges. This limitation could probably be overcome in plant scale wet oxidation units by means of adequate agitation. The presence of cations from chemical stabilization of phosphorus appears to catalyse wet air oxidation.

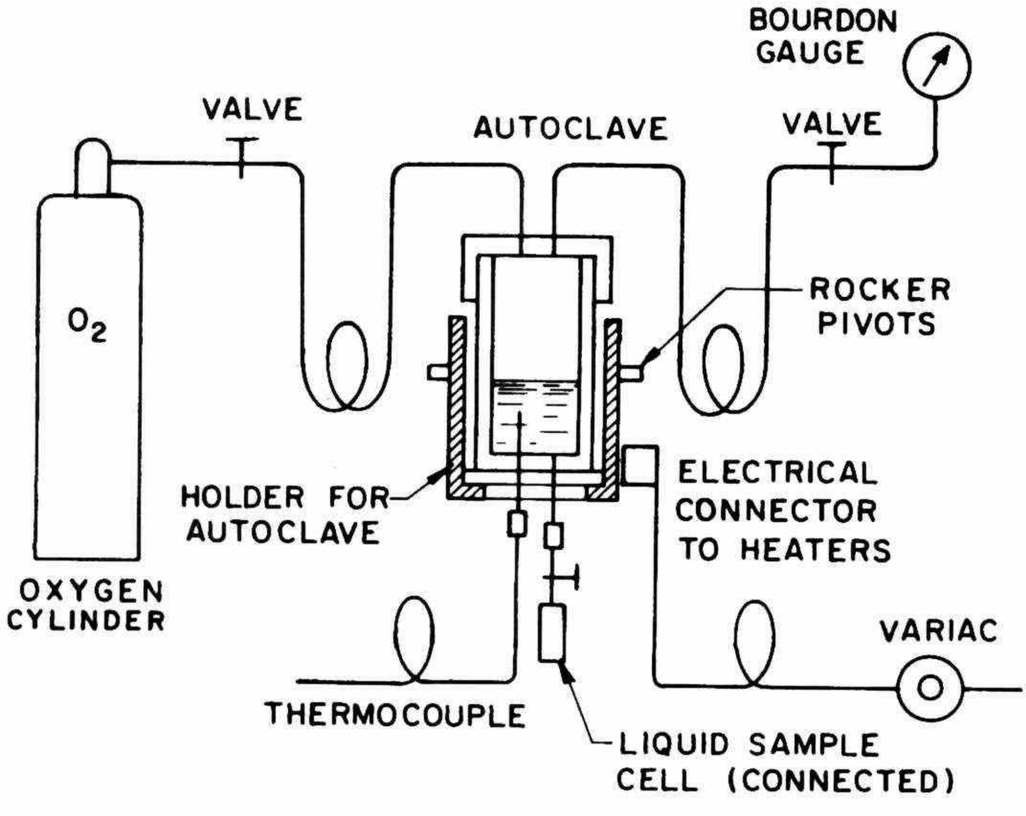
Wet air oxidation of chemical sludges reduced the stabilization of phosphorus achieved by prior chemical treatment; wet air oxidation of

PHOSPHATE LEVELS IN SUPERNATANT AND SOLIDS BEFORE AND AFTER WET AIR OXIDATION

Run	Sludge	Temperature ^{o}F	Filtrate - ppm*		Solids - % Weight**	
			Before	After	Before	After
17	Drury Lane - Primary	500^{o}	2.0	0.3	1.0	4.6
5		550^{o}	1.7	10	1.3	
8	Elizabeth Gardens - Primary	450^{o}				7.3
14		500^{o}	5.0	4.2	2.4	2.9
6	Elizabeth Gardens - Activated	450^{o}	0.9	4.3		2.6
7	North Toronto - Primary	500^{o}	27	1.7	2.0	5.2
13	North Toronto - Primary	500^{o}	0.2	1.9	3.5	2.7
2	with $FeCl_3$	550^{o}				1.6
4	Sarnia - Primary	450^{o}	1.3	13	0.89	2.00
10	with $FeCl_3$	500^{o}		11		1.5
3	Newmarket - Primary with Lime	450^{o}	2.0	19	1.0	1.5

* as orthophosphate

** as total phosphorus



SCHEMATIC DIAGRAM OF APPARATUS

non-chemical sludges showed contradictory evidence of increased and reduced stabilization.

Sludge containing high levels of chemicals may give rise to carbonate formation during sludge oxidation. With lime sludges, the carbonate was stable at $500^{o}F$. This sludge could cause a fouling problem in full scale plants.

Recovery of a high yield of phosphorus in the form of residual ash from wet oxidation appears possible.

Further work is recommended to establish the kinetics of wet air oxidation more fully, and to study the behaviour of phosphorus during wet oxidation.

This report also includes a literature survey of wet air oxidation material with specific reference to the project objectives. The design and operation of the rocking bomb oxidation autoclave are described, as well as tests of its performance.

Authors: R.R. Hudgins and P.L. Silveston, Department of Chemical Engineering, University of Waterloo, Waterloo, Ontario.

Project No. 72-5-5

79 p., figures, tables

RESEARCH REPORT NO. 20

EVALUATION OF THE BARBER-COLMAN WETOX PROCESS FOR SEWAGE SLUDGE DISPOSAL

Ontario Research Foundation

Conventional methods for sludge disposal include land spreading, heat treatment, wet oxidation, dewatering, incineration and landfill.

With the critical shortages of land space in and near cities, the pressure to cut the soaring cost of operating sewage plants, and the imposition of more stringent pollution regulations, there is an urgent need to improve the efficiency of existing conventional methods for sludge disposal and, at the same time, to develop new, efficient, lower-cost methods. Recently, Barber-Colman Company announced the development of the Wetox process. This process, based on the principles of wet air oxidation, differs from the existing Zimpro processes in both reactor design and performance.

The "bound water" content of sewage sludge is 90-98%, the higher value being associated with waste biological sludge from secondary treatment processes. In most cases, the sludge is digested anaerobically to reduce its solid content by approximately one-third, with the generation of a methane-rich, low-grade fuel gas as a by-product. The digested sludge is still voluminous, contains residual pathogens as well as high concentration of organic matters, and is as difficult to dewater as the raw sludge. All the sludges, either raw or digested, must be ultimately disposed.

There are many sludge disposal processes, either now in use or still under development. Evaluations of the most common processes used have been summarized in the report. Most of the new methods for sludge disposal emphasize producing re-usable by-products rather than straight destruction of organics. Examples of these methods include acid hydrolysis, biological fractionation, pyrolysis, freezing, the Scheel process and the worm process.

Both the Wetox process and the Zimpro processes (Zimpro high temperature-pressure and Zimpro low temperature-pressure) are based on the principle of wet air oxidation. This is a chemical reaction occurring in a liquid medium between oxygen and suspended or dissolved combustible matter. Wet air oxidation is more difficult to initiate and sustain than direct combustion unless conducted at temperatures above the normal boiling point of water. Therefore, it is achieved in a pressurized chamber wherein a liquid and its vapour are confined with oxygen gas under conditions more favourable than those obtainable under normal ambient conditions. Even under pressure, wet air oxidation occurs sluggishly and is liable to be incomplete unless provisions are taken to assure effective transfer of oxygen gas to the combustible matter.

The process is a convenient way to destroy organic waste contained in water without evaporating or otherwise removing the water from the organic matter, as required before incineration. The reduction of air pollution is effected in wet oxidation because the products of combustion are automatically and thoroughly scrubbed. In wet air oxidation, usually less than one-third as much heat is expended in preparing the organic matter for oxidation as in the case of evaporation/incineration.

COMPARISON BETWEEN DRY INCINERATION AND WET AIR OXIDATION

DRY	WET
- Low-moisture Fuel	- Watered Fuel
- Low-pressure Air (slightly above atmospheric pressure)	- High-pressure Air (usually 400-2000 psi or 2758-13790 kPa)
- High Temperature Ignition (usually 1400-1600°F or 760-871°C)	- Low Temperature Ignition (usually 350-550°F or 177-288°C)
- Oxidation	- Oxidation
- Heat Combustion	- Heat Combustion
- Auto-oxidation	- Auto-oxidation
- Air Pollution	- Reduced Air Pollution
- Need Incinerator	- Need Wet Oxidation Reactor
- Heat Recovery	- Heat Recovery with Power or Electricity Generation

In both the Wetox and Zimpro processes, the actual combustion of the organic compounds is an exothermic reaction; therefore, provided there is enough organic matter present, it can proceed autogenously once oxidation is initiated. Combustion is self-sustaining and, in fact, the excess heat from large wet air oxidation systems has been used to generate power and electricity.

An investigation was carried out to evaluate the suitability of the Barber-Colman Wetox process for municipal sewage sludge disposal. Technical and economic data for the Wetox process were gathered through literature, special correspondence, and pilot plant visits, as well as some experimental and analytical work performed at the Ontario Research Foundation (ORF) laboratory. These data were then analysed and compared with those of other sludge disposal methods, particularly the Zimpro process, since the Wetox process is rather similar in operation.

Based on the evaluation of a limited amount of laboratory and pilot plant data, it appears that the Wetox process is simple to operate at $450^{o}F$, 600 psi ($\sim 232^{o}C$, 4137 kPa) with 0.3% sulphuric acid. The process is suitable for sewage sludge disposal, although no commercial scale Wetox plant has yet been built. Furthermore, Wetox can achieve similar sludge destruction efficiency, i.e. approximately 80% destruction of suspended solids and 65-82% reduction in COD, but at a lower temperature and pressure than the corresponding Zimpro process. This is believed to be due to the design of the Wetox reactor, which ensures adequate oxygen transfer into the sludge, as well as the addition of a small amount of sulphuric acid to speed up the oxidation.

For larger scale sludge disposal (e.g. 100 tons or $\sim$ 91 metric tons dry solids per day), the total disposal cost (i.e. from digested sludge to ultimate land disposal), on per ton dry solids basis, via the Wetox process can be as low as \$21 ($\sim$ \$23 per metric ton). Realizing that only the major expenditure items are included in the cost estimates and other "hidden" costs may exist, the estimated cost of \$21 is judged to be only approximate and probably low. Nevertheless, the Wetox cost is at least competitive with the low temperature-pressure Zimpro route, as well as with other more conventional sludge disposal processes.

The Wetox process is easier to operate than the high temperature-pressure Zimpro process and involves less process steps than most other conventional processes. For a really small size Wetox system (e.g. 6 tons or $\sim$ 5.4 metric tons solids per day), semi-batch units may be used and further cost savings may be realized. Alternatively, small scale continuous or semi-batch units may be designed to operate at slightly high temperature-pressure, say 485°F and 750 psi ($\sim$ 252°C, 5171 kPa), without too much increase in cost but may improve the destruction efficiency by approximately 10%. It is also noted that the Wetox process may have high potential for sludge disposal in small communities where land spreading is unsuitable.

Because only a limited amount of laboratory and pilot plant Wetox data are available, the aforementioned conclusions should be viewed as tentative until they can be verified with data obtained by further experimentation. Actual scale-up of the Wetox process may alter the sludge destruction efficiency and hence the cost. At any rate, more experimental work and the development of hardware such as heat exchangers, pumps, stirrer-drive, etc., will be required before Wetox plants can be commercialized.

In order to increase the confidence level of ORF's evaluation, a few Wetox experiments should be carried out independently. Potential operational problem areas should be investigated. For example, contaminants in non-condensable gases exiting from the Wetox should be analysed to determine if the gases require incineration before discharge into the atmosphere. The disposal of the mixture of lime sludge and inert residual solids precipitated from the Wetox effluent should also be tried experimentally. From these experimental data, a more detailed cost analysis can be made and the performance results thus obtained should indicate closely the feasibility of using such a process for chemical-organic sludges.

Authors: P. Seto, Department of Environmental Chemistry, and D.K. Smith, Department of Applied Chemistry, Ontario Research Foundation, Sheridan Park, Mississauga, Ontario.

Project No. 73-5-6

75 p., figures, tables

RESEARCH REPORT NO. 24

LAND DISPOSAL OF SEWAGE SLUDGE

VOLUME II

(April, 1973 - March, 1974)

University of Guelph

Sewage and sewage sludge have been applied to agricultural land for many years, but until recently, there has been little concern about resulting pollution of water with nutrients and heavy metals.

The objectives of the project described by this report were to determine the maximum rates of sludges, resulting from chemical treatment for phosphorus removal, which may be applied to agricultural soils without polluting ground and surface waters with elements or organisms pathogenic to humans and animals, and without reducing the quantity or quality of the crops produced. The chemicals most commonly used for phosphorus removal in sewage treatment plants are calcium oxide or hydroxide, aluminum sulphate, and ferric chloride. There has been little, if any, information published previously on land application of sludges resulting from these treatments.

This report covers work done by the Departments of Land Resource Science and Microbiology at the University of Guelph on land disposal of sewage sludge from April 1, 1973 to March 31, 1974.

Runoff studies were conducted with sewage sludges applied in Fall, Winter and Spring; field rate and source of sludge studies were carried out with bromegrass on a loam soil and with corn on a loam, a sandy loam and a clay loam soil. A greenhouse trial with different rates and sources of sludge on two soils at three pH levels is also reported. Fluid digested sewage sludges from calcium oxide treatment of Newmarket sewage, aluminum sulphate treatment of Point Edward sewage and ferric chloride treatment of North Toronto sewage were used. Chemical analyses of the sludges, soil nitrogen, crop yields and nutrient and metal content of crops are presented along with microbial studies of the sludges and the crops grown. Detailed descriptions of the soils used are also presented.

There was a marked growth response to the aluminum sludge in the greenhouse and in the field bromegrass trial. Corn yields were increased by sludge application at the Elora and Milton sites.

An exception to the above occurred in three traials where a poor growth response to the aluminum sludge from Point Edward was observed. Nitrification studies and plant nutrient analyses suggested that, when applied at the same rate of total nitrogen as the other sludges, the Al sludge supplied less available nitrogen to the crops. Aluminum can be toxic to plants, but there was no evidence of this in the greenhouse trials. However, in most of the trials crop yields did not increase with increasing rates of the Al sludge, suggesting that some toxic factor was involved. None of the nutrients or metals analyzed appeared to be the cause. It is probable that some other consitutent of the Point Edward sludge, unrelated to aluminum treatment, was involved in its apparent toxicity to plants.

The sludges applied resulted in rather small applications, on an acre basis, of the elements chromium, mercury, manganese, and nickel, and no effect of these metals was noted in the concentrations in plants. Somewhat larger amounts of lead were added with the North Toronto sludge, but did not affect the content of plants. Little effect was expected in this first year of application.

Zinc and copper contents of the sludges were lower than those reported for a number of Ontario sludges, but affected concentrations in plants to some extent. In the greenhouse trial, sludge did not affect the zinc concentration in barley at low soil pH. At high soil pH, the zinc concentrations were lower than at low pH. However, at high pH the zinc concentration in barley increased with increases in rate of sludge, and this also occurred in the corn trials. In the greenhouse, copper increased with increasing rates of sludge. Zinc and copper are known to cause problems after continued applications of high rates of sewage sludge. While the concentrations in plants were far from toxic in these trials, it was not expected that concentrations would be affected in the first crop with the quantities of copper and zinc applied.

Although it has always been known that sewage sludge contains appreciable phosphorus, it is also well known that mineral soils have an exceptional capacity to bind this element. There has been little suggestion

that phosphorus content might limit rates of sludge application. The amounts of phosphorus applied in the sludges used in this study were from 2.5 to 3.5 times as high as the highest rate recommended for corn in Ontario. Some effort will be required to determine how long it will take for these rates of phosphorus to exceed the fixation capacity of Ontario soils.

A considerable quantity of nitrate-nitrogen remained in the soil profiles at the end of the growing season (October sampling). This nitrate-nitrogen not absorbed by the crop may be leached to the subsurface water and/or lost as a gas through denitrification.

There has been some concern that the application of sewage sludges, particularly calcium sludge, would affect boron availability. It seemed possible that boron might be less available with the high pH resulting from the use of the calcium sludge. However, in the greenhouse trial, boron concentration increased slightly with increasing rates of calcium sludge. There was little effect of the sludges on boron concentration in corn. Boron is readily leached and is therefore not likely to build up in Ontario soils from year to year. On the basis of this limited experience, it does not seem likely that the use of sludge at moderate rates under Ontario conditions will cause serious deficiencies or toxicities of boron. In drier climates it is possible that boron would accumulate in the soil profile.

Studies at this stage have not conclusively demonstrated increased populations of indicator organisms on plants or in runoff waters from sludge treated soils.

Runoff losses in 1973 were generally less than would be expected in a normal year. High rates of application greatly increased nutrient runoff and this emphasizes the importance of restricting application rates to soil requirements for crop growth. Metals losses were small with the sludges and rates used in this study.

Sewage sludge has a reputation for being variable in composition and this is a major concern in the development of recommendations for its use on farm land. It is difficult, if not impossible, to recommend optimum or even permissible rates of an unknown product. The truckloads of sludge sampled and analyzed in these studies were a very small sampling

of what is spread in Ontario. In the analyses performed, the samples of the calcium sludge from Newmarket illustrated the variability problem and the samples of the iron sludge from North Toronto illustrated the type of uniformity in composition which is desirable. If the degree of uniformity in composition apparently attained at the North Toronto plant could be attained across the entire province, a very serious problem in the acceptance of use on agricultural land would be solved.

Author: Departments of Land Resource Science and Microbiology,
University of Guelph, Guelph, Ontario

Project No. 72-5-17

276 p., figures, tables

RESEARCH REPORT NO. 25

HEAVY METALS IN AGRICULTURAL LANDS RECEIVING CHEMICAL SEWAGE SLUDGES

VOLUME II

University of Toronto

Volume I report on this subject (COA Report No. 9) dealt with:

(1) sludge heavy metal characterization of North Toronto, Newmarket and Point Edward sewage treatment plants;
(2) heavy metal contamination of farm soils and vegetation resulting from sludge applications (Newmarket area);
(3) surface water, heavy metal contamination resulting from sludge disposal; and,
(4) assessment of analytical data.

During 1973-1974, work was continued in all these subject areas and is described in Report No. 25, Volume II of COA Project 72-5-3. Heavy metal contamination studies of soils, vegetation, groundwater and surface water were carried out at the Burlington Skyway plant disposal farm and the North Toronto plant disposal area. A study of garden vegetable contamination due to the use of sludge for home gardening was also initiated.

Again, as in the previous year, emphasis was placed on using standard reference materials to give validity ot the analytical data.

The following conclusions are made in this volume:

(a) Plant Uptake of Metals.

There is little evidence of high heavy metal uptake by vegetation. An exception occurred in the case of mercury levels found in tomato fruit and possibly bean pods grown on sludged soil. In this instance, on a dry weight basis, the mercury levels were found to be 20 times or more than in the control samples. On a wet weight basis, the mercury levels in tomatoes would be up to 1 ppm.

Zinc and copper, in most cases, were elevated in vegetation grown on sludged land. Here, however, the increases were generally less than twice the control plant levels.

Work has been initiated to improve the lower limit of cadmium detection in these sample matrices. It will be important to continue methods development research related to cadmium.

All soils and sludges used above were alkaline in pH (a common situation in southern Ontario). Uptake from acidic soils is more probable and this possibility should be explored.

(b) Surface Contamination of Vegetation by Sludge.

Perhaps the most serious potential problem comes from surface contamination of vegetation. Research showed that unless vegetation was scrupulously washed (i.e. rub surfaces with fingers and use a mild detergent) elevated metal levels for vegetation were recorded. It is well known that most people do not wash vegetation with detergent as indicated above. In the case of forage crops, sludge is commonly applied after sprouting and, hence, can easily remain on the plant surfaces to be ingested by farm or wild animals.

(c) Plant Age vs. Metal Content.

In general, a decrease in metal content with increasing age of vegetation was noted.

Conclusion from Inspection of Groundwater near Sludge Disposal Areas

On the whole, the North Toronto well results showed large variations in iron and zinc values and little variation in copper and nickel values within the period of study. Iron appeared to be most strongly affected by filtration and copper and nickel least. Zinc, from time to time, showed increasing values with decreasing porosity of the filter medium.

Author: J.C. Van Loon, Associate Professor, Institute for Environmental Studies, University of Toronto, Toronto, Ontario

Project No. 72-5-3

41 p., figures, tables

RESEARCH REPORT NO. 27

EXAMINATION OF SEWAGE AND SEWAGE SLUDGE FOR ENTEROVIRUSES

VOLUME I

Ontario Ministry of Health

A promising and practical method for taking advantage of the nutrient qualities of sewage sludge is to spread it on agricultural or grass land in rural areas. This method, however, carries an inherent risk that the environment may be polluted further with harmful agents such as viruses and heavy metals. This report deals with the first phase of a virus monitoring programme being carried out in the Enterovirus Laboratory of the Ontario Ministry of Health, Laboratory Services Branch, in connection with the plans to spread urban sewage sludge on rural land in Ontario.

The results of this programme include virus surveillance studies on five Ontario plants which employ different phosphate removal techniques, as well as related laboratory studies.

Gauze pad collections of sewage samples or sludge samples, collected in 100 ml volumes soon after mixing tank contents, were transported to the laboratory without delay. The specimens were extracted with alkaline Earle's balanced salt solution (pH 0.5) and the extract decontaminated by chloroform treatment. The aqueous layer, freed of residual chloroform, was tested for viruses in primary and continuous cultures of monkey kidney and human diploid fetal lung (WI-38) cells at least three times and the presence of virus demonstrated by cytopathic effects and electron microscopy, as well as haemadsorption and interference testing. Any isolate was identified with pools of specific antisera to enteroviruses. In the case of poliovirus isolates, genetic marker and antigenic differentiation tests to distinguish between vaccine and virulent strains are in progress.

During April, 1973 - December, 1974, a total of 900 specimens including 438 sewage specimens, 398 raw and digested sludge specimens

and 64 specimens of water were investigated. Out of the 444 specimens tested in 1973, 40% of the sewage specimens (48/124) contained viruses, although the collection period included several cold months during which enteroviruses were not detected in the community. Virus isolation rates in 1974 were lower, reflecting the generally lower isolation rates from clinical cases as well. Viruses from sewage included several poliovirus isolates. Preliminary results indicate that at least one strain is definitely not related to vaccines and that perhaps a few others are intermediate in character, indicating that they too could be of non-vaccine origin. All the non-polio enteroviruses in this study are well known human pathogens and, therefore, it is important to ensure that they are inactivated before sludge is spread on soil.

Rapidly growing cities and towns produce large amounts of sewage, outstripping existing disposal facilities in some cases. The amount and nature of the sewage produced by each community is influenced by a number of factors, including population density, standard of living and level of industrialization. Adequate sewage treatment is expensive but uncontrolled sewage disposal leads to undesirable consequences. While the serious environmental damage which might occur in the long run is of great concern, it should not be forgotten that residential sewage, rich in faecal material, often contains dangerous viruses and bacteria, such as the agents of hepatitis and typhoid.

It appears that raw domestic sewage has a protective effect on enteroviruses, perhaps because of the stabilizing influence of organic matter. In assessing the adequacy of sewage treatment, it is also important to remember that faecal matter and other solids present in sewage might contain adsorbed viruses which are hard to recover. As a consequence of the affinity of viruses for solids, viruses entering sewage are likely to be associated with faecal and other solids. They are, thus, likely to end up in the solid residue of sewage viz. sludge, from which they may be recoverable only under special conditions. If the sludge is rich in phosphates as a result of phosphate removal operations, the likelihood of viruses being present is even greater since nascent phosphate precipitates are excellent virus adsorbents.

It has been estimated that the daily accumulation of wet sludge in urban centres amounts to approximately ten litres per person, so that a city of 100,000 is faced with the disposal of a million litres of sludge every day. Safe disposal of such amounts of sludge should include efficient virus inactivation in view of the high probability of the presence of viruses. While some pollution control plants incinerate the sludge before disposal, there can be little doubt that it would be preferable to recycle the nutrients in sludge by spreading it on agricultural land, if this can be done without damaging the land and endangering the health of people and livestock.

It can be said, guardedly, that spreading sludge probably poses only a low level health hazard. It is, however, unwise to make a defintive judgement in view of the low virus prevalence in the community and the absence of practical detection methods for hepatitis and gastroenteritis viruses.

Contractor: Ontario Ministry of Health, Toronto, Ontario

Project No. 72-5-1

35 p., tables

RESEARCH REPORT NO. 28

REMOVAL OF PHOSPHATES AND METALS FROM SEWAGE SLUDGE

University of Waterloo

With the advent of chemical treatment for the removal of phosphates in wastewater treatment plants, the sludges produced from these plants will now contain the bulk of the phosphate in the orignial influent streams. In addition to its phosphate content, the sludge will also contain most of the metallic cations entering in the influent stream, as well as the metallic cations such as iron or aluminum which may have been added as treating chemicals to effect phosphate removal, or as coagulants.

The role of metals, particularly the heavy toxic metals such as copper, chromium and zinc in the sludges, is not yet completely appreciated. The metals become concentrated to a considerable degree in the sludge and some of them frequently reach appreciable levels (e.g. 5% by weight of dry solids or more). The case of anaerobically digested sludge is particularly interesting because of the reduction in sludge volume during digestion and the correspondingly increased metal content. It is, therefore, questionable whether sludges from anaerobic digestion can be used repeatedly for agricultural purposes on a given piece of land. There is also evidence that leachates and runoff waters from sludge land disposal sites may contain undesirably high quantities of dissolved heavy metals and of phosphates.

Two problems can be identified with respect to the metals and phosphate content of sludges and the ultimate disposal of the sludge. If it were possible to remove most of the heavy metal content from the sludge, this might be desirable, particularly in cases where the sludges are to be used for agricultural purposes or where there is more than a normal contamination with heavy metal impurities. In addition, there is the possibility that if iron or aluminum has been added for phosphate removal, these metals could be recovered and recycled within the treatment plant. The high phosphate content of sludges is sometimes also undesirable,

for some of this material can leach out from sludge disposal sites, particularly if the sludge is fairly alkaline or fairly acid, and groundwaters may feed the phosphate pollution back into the watershed system. If the sludge is incinerated, then the ash from the incinerator will be rich in phosphate and heavy metals and may well be a source of these materials, particularly for recycling the iron or aluminum for further use in phosphate removal.

The principle objectives of the work recorded in this report fell into two categories. The first part of the study involved leaching of sludges from processes using iron or alum for phosphate precipitation. The second part of the study involved an examination of the extract from the leaching of the sludge in order to determine methods of extracting phosphate, iron or aluminum, and other metals from it. In this examination of the extract, particular attention was to be paid to the possible role of solvent extraction as a means of making separations between metallic cations, or of extracting phosphate from the aqueous extract.

A process has been developed whereby metals and phosphates can be extracted with acid from anaerobically digested sludges. The acid extract can be neutralized under controlled conditions of pH to yield a solid product low in organic material containing mostly iron and aluminum phosphates. Iron and phosphate can be separated and recovered from the crude inorganic product by known solvent extraction technology, or by alkali treatment. By proper control of pH, it is possible to produce two solid products, one containing most of the iron and aluminum, and one containing most of the heavy metals.

Cost of removing most of the metals and phosphate from anaerobic sludges are estimated to be \$30-\$35 per million gallons of influent (activated or mixed sludges were not tested in this study). Separation and recovery of iron and phosphate from the metal-phosphate solid product is estimated to yield a net income of about \$10 per million gallons of influent. Therefore, if removal of metals and phosphates is practiced, it is profitable to recover and recycle the iron (or aluminum) and phosphate from the crude inorganic product rather than disposing of it.

This research was supported, in part, under provisions of the Canada-Ontario Agreement on Great Lakes Water Quality. Additional support was received from the National Research Council of Canada.

Authors: D.S. Scott and H. Horling, Department of Chemical Engineering, University of Waterloo, Waterloo, Ontario

Project No. 73-5-7

55 p., figures, tables

RESEARCH REPORT NO. 30

HEAVY METALS IN AGRICULTURAL LANDS RECEIVING CHEMICAL SEWAGE SLUDGES

VOLUME III

Institute for Environmental Studies
University of Toronto

This report is divided into two subject areas:

A. Analytical Methods Development for Metals.

B. Sludge Analysis for Metals.

In category A, work was centred on atomic absorption and electrochemical (anodic stripping and polarographic) methods. Methods development work gives emphasis to "total" metal analysis because of a lack of proven procedures for such important elements as As, Se, Mo, etc. Procedures developed specifically for these elements are included in the report.

There has been an interest in evaluating the potential of electrochemical techniques, particularly polarography and anodic stripping, for sludge analysis. These techniques were investigated and results and preliminary conclusions are presented.

Flameless atomic absorption is considered to be important for the analysis of sludge. This technique may have an important application in the determination of total metals which are difficult to analyse by flame methods. However, flameless atomic absorption is investigated as a possible method of identifying the forms of metals which occur in sludge. In this regard, a quartz "T" tube furnace has been developed which can be used for thermal volatility studies and gas chromatographic studies of metal compounds in sludges. As a spin-off benefit of this study, data will be obtained for potential metal losses to stack gases because of incineration, if this method is used for sludge disposal. Early results of this investigation are included in this report.

In category B, available chemical sludges are being routinely analysed for metals. A tabulation of results from four new sewage

treatment plants in Ontario is included in this volume.

Volumes I and II of this study were published as Research Reports No. 9 and 25 in the Canada-Ontario Agreement Series.

Author: J.C. Van Loon, Associate Professor, Institute for Environmental Studies, University of Toronto, Toronto, Ontario.

Project No. 72-5-3

37 p., figures, tables

RESEARCH REPORT NO. 31

SLUDGE INCINERATION AND PRECIPITANT RECOVERY

VOLUME I

A Selective Coded Bibliography

Wastewater Technology Centre
Environmental Protection Service
Fisheries and Environment Canada

Incineration has been a popular method for ultimate disposal of sewage sludges for many years. More recently, with the implementation of chemical phosphorus removal programs at municipal wastewater treatment plants, interest has developed in recovery and recycle of the chemical precipitants (alum, iron and lime) for the incinerated sludge ash. In 1972, the Wastewater Technology Centre of the Environmental Protection Service initiated a "Sludge Incineration and Precipitant Recovery Program". This program continued with funding provided under the Canada-Ontario Agreement on Great Lakes Water Quality. An extensive review of the related literature was performed as part of this program and is presented in this report.

This bibliography summarizes a large portion of the significant English language literature from the period 1968 to 1974. It also includes earlier prominent literature. The papers, reports, or books cited have been reviewed, categorized according to thevarious aspects of incineration, and systematically coded. The categories used include:

Sludge Conditioning, Dewatering and Disposal
Combustion Theory
Design and Operation
Fluidized Bed Incinerator
Multiple-Hearth Incinerator
Rotary Kiln
Process Characteristics (including ash, sludge, emissions, effluents)
Precipitant Recovery (including chemical reactivation)
Miscellaneous (including spray drying, wet air oxidation, etc.)

The references are also coded at a secondary level with respect to the scale of the study and, where applicable, the references are categorized according to the type of data presented.

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Project 72-3-4

31 p., subject index tables, bibliography

RESEARCH REPORT NO. 33

THE REMOVAL AND RECOVERY OF METALS FROM SLUDGE AND SLUDE INCINERATOR ASH

Water Chemistry Section
Process Research Division
Canada Centre for Inland Waters
Fisheries and Environment Canada

Previous investigations on this subject have dealt with one type of sludge and one type of sludge incinerator ash. Since sewage treatment procedures vary for different facilities, and different methods of sludge conditioning and phosphorus removal are used, it is possible that metal recovery may be more efficient from one type of sludge than another. Similarly, factors such as incineration temperatures may affect the leachability of metals in incinerator ash. Therefore, this recovery study was conducted on as many different types of sludge and ash as was possible to collect. Samples of digested sludges were collected from eight activated sludge sewage treatment facilities in southern Ontario. Sludge ash samples which had been incinerated at various temperatures were also obtained. An experimental program was designed to systematically investigate metal removal and recovery from these samples.

The electrochemical plating of Cu, Zn, Ni and Cd from aqueous solutions was studied using standard plate type electrodes and improved efficiencies were attained with fluidized bed electrodes. Because direct electroplating from sludge was found to be inefficient, acid and base additions were made to solubilize the metals prior to plating.

Most of the metals and phosphorus in the digested sludge could be dissolved by adding sufficient H_2SO_4 or HCl to lower the sludge pH to 1.5. The average cost of acid required per ton of dry solids was $41 for H_2SO_4 and $77 for HCl. Little economic advantage would be gained by recovering sludge constituents, since processing costs for the large volumes of dilute leachate would be high. Therefore, the removal of heavy metals from wet sludge to reduce their toxicity does not appear to be economically feasible.

The metals and phosphorus in sludge incinerator ash can be solubilized with H_2SO_4 in a countercurrent stepwise process which uses most of the acid. Further processing of the H_2SO_4 leachate for recovery of valuable constituents was complicated by the presence of large quantities of iron in the leachate. Neutralization of the leachate with NaOH precipitated all the metals and phosphorus. Treating this precipitate with a hot NH_4OH - $(NH_4)_2SO_4$ mixture resolubilized most of the trace metals and phosphorus, leaving iron oxide in the solid phase. Electroplating removed Cu, Zn, Ni and Cd from the ammonia leach, and ammonium phosphate was recovered from the solution after electrolysis. While processing costs for incinerator ash would be much less than those for wet sludge, the procedure does not appear to be economically viable.

The best method for disposing of wet sludge and making use of its valuable constituents is to spread it on agricultural land. Unfortunately, because of high concentrations of some heavy metals in sludge from industrialized areas, this method poses severe environmental hazards. It was demonstrated that recovery of toxic trace metals from wet sludge is not economically feasible. Elimination of metal discharges into sewers at the source is apparently the only practicable solution.

It was found that changing the sludge incineration temperature had a considerable effect on the leachable metals and phosphorus in the ash. By a judicious choice of incineration conditions, any municipality should be able to minimize the environmental impact of landfilling sludge incinerator ash.

It is recommended that the recovery of phosphates and metals from incinerator ash be attempted only when a positive economic benefit can be accrued. The method for recovery of phosphates and metals described in this report does not appear to be economically viable except for very large plants. Further experimentation is recommended on direct NH_4OH - $(NH_4)_2SO_4$ leaching of the ash at high temperatures and

pressures, such as those employed in the mining industry. This may lead to a cheaper method of extraction.

Authors: Barry G. Oliver and John H. Carey, Water Chemistry Section, Process Research Division, Canada Centre for Inland Waters, Fisheries and Environment Canada, P.O. Box 5050, Burlington, Ontario.

Project No. 74-3-15

58 p., tables, figures.

RESEARCH REPORT NO. 35

LAND DISPOSAL OF SEWAGE SLUDGE

VOLUME III

(April, 1974 - March, 1975)

Departments of Land Resource Science and Microbiology
University of Guelph

This report covers runoff studies with fall, winter and spring applied sewage sludge, and field rate and source of sludge studies with bromegrass on a loam soil and with corn on a loam, a sandy loam and a clay loam soil. A greenhouse trial with different rates and sources of sludge on two soils at three pH levels is also reported. Fluid digested sewage sludges from calcium oxide treatment of Newmarket sewage, aluminum sulphate treatment of Kitchener sewage and ferric chloride treatment of North Toronto sewage were used. Chemical analyses of the sludge, soil nitrogen, crop yields and nutrient and metal content of crops are presented along with microbial studies of the sludge and the crops grown. Detailed descriptions of the soils used are also presented.

The 1974 season was a difficult one for growing crops in the field. The spring was unusually rainy, with fewer days available for sludge application, tillage and seeding than normal, resulting in later seeding than was desirable, particularly at the Milton site. A shortage of soil moisture towards the end of the season added to the problems.

Although many of the results reported are still preliminary, there are several trends developing.

The objective of this research is to determine maximum rates of sewage sludge application which can be used on agricultural soils without contaminating subsurface water with nitrate nitrogen and surface waters with elements or organisms pathogenic to humans and animals, and without reducing the yield or quality of the crops produced.

In runoff studies, losses of nitrogen and nutrients were low in 1974, lower than 1973. One runoff event immediately following fall sludge application resulted in appreciable losses of nutrients, metals and COD.

In the field, crop responses to the sewage sludge were similar in most cases to those from chemical fertilizers. The three chemically treated sludges produced similar yields, although the iron sludge tended to advance early growth and maturity of corn slightly. In one trial, where soil structure was a problem, sludges produced appreciably higher yields than chemical fertilizers. There was no evidence of poor growth with the aluminum sludge in 1974 in any of the trials. In the greenhouse, sludge at high rates of application caused salinity problems when the soils were not leached. Salinity is not expected to cause problems in the field in Ontario, but could pose a serious problem in dry areas of western Canada.

The calcium sludge tended to increase soil pH in the field and greenhouse even on soil of pH 7.1. The aluminum and iron sludges lowered soil pH, but less than one quarter as much as similar rates of nitrogen from ammonium nitrate.

In general, about twice as much nitrogen appeared to be required from sludge as from ammonium nitrate to produce a particular yield or nitrogen content in grass or corn in the field in 1974. One might expect that, as each year passes, the sludge nitrogen would compare more favourably with ammonium nitrate due to the gradual release of nitrogen from the accumulation of organic matter. Nitrate nitrogen concentrations in grass and corn stover approached toxic levels for animals at the highest rates of sludge application.

Sludges increased sodium bicarbonate extractable ("plant available") phosphorus in soil quite markedly. This effect was appreciably greater with the calcium sludge although it supplied less total phosphorus than the other sludges in most cases. Phosphorus concentration in crops was slightly higher with the calcium than with the other sludges, but even the lowest rates of sludges produced adequate phosphorus concentrations in plants and increasing rates of sludge did not, in general, increase phosphorus concentrations.

The phosphorus in calcium sludge appears to be appreciably more available in Ontario soils than that supplied in iron or aluminum sludges. With the large amounts of phosphorus in sludge, this greater availability may be a disadvanatage where sludges are applied repeatedly to the same land.

The Midland sludge supplied appreciably more boron than other sludges and could pose a toxicity problem if used at high rates for certain crops, or if used in dry areas where boron could accumulate.

Cadmium concentrations were quite low in the field trials but the use of high cadmium sludges in the greenhouse resulted in appreciable uptake. Of particular concern was the high cadmium concentration in the second crop of grass on the treatment, which received only one application of sludge at the 1600 kg N/ha rate before the first crop was seeded. This produced higher cadmium concentrations than two applications of 1600 kg N/ha, one before seeding each crop. Thus, cadmium appeared to become more available with time after application.

Copper concentrations were increased by sludge applications, increases, being, in general, related to copper additions. The sludges which were used in the field trails were low in copper. They increased copper content of crops by no more than the increase with ammonium nitrate.

Nickel concentrations in crops increased quite markedly with addition of nickel in sludges. The calcium sludge from Midland, high in nickel, increased concentrations of nickel in ryegrass quite markedly even at high soil pH. Nickel, like cadmium, appeared to become more available with time.

Zinc concentrations were increased by sludge additions in the field and greenhouse, although in the greenhouse some low zinc sludges also reduced zinc concentrations in grass, probably by raising soil pH. At high rates of application, zinc appeared to become more available with time after application in sludge.

Potassium, calcium, magnesium, manganese, iron, aluminum, chromium and mercury concentrations in crops were all significantly affected by treatment in one or more trials but effects were variable and small. There was no evidence that aluminum sludges produced high aluminum concentrations in crops. Chromium concentrations in crops increased quite appreciably on a percentage basis in one trial but the concentrations were still quite low.

In the field trials, less nitrate accumulated in the soil under grass than under corn. More nitrate appeared to be produced by sludges

containing the largest portion of their nitrogen in ammonium form. In general, nitrate concentrations in soil solution were quite high, but movement was less than in 1973, probably due to the lower rainfall in July and August in 1974. The nitrate concentrations were much greater in the silt loam and clay loam profiles than in the sandy loam, for reasons that are not clear. In the fall of 1973, nitrate appeared to be lost from the clay loam profile, probably by denitrification, but in 1974 there was no apparent loss.

In laboratory nitrification studies, nitrate production continued for at least 52 weeks. The rate of nitrate production varied among sludges but differences were not related to chemical treatment applied to sewage for phosphate control or to ammonium content. The Point Edward aluminum sludge collected in 1973 gave a low rate of nitrate production. The Point Edward iron sludge collected in 1974 also gave a low rate of nitrate production, although not as low as the 1973 sludge.

Comparisons of various chemical extractants as measures of metal availability to plants show acetic acid as a promising extractant for nickel. Further work is required on the other metals.

Iron in the iron sludge is crystallized, based on chemical extraction, microprobe analysis and X-ray. Where the sludges have been applied on the soil surface in the bromegrass trail, the ferric phosphate crystals appear to be decomposing and the iron may chelate with organic matter.

Where the sludge has been surface applied, calcium, aluminum and iron all appear to be moving into the soil; calcium has moved up to twelve inches in two years.

Examination of the sludges before application to soil show inorganic minerals and particulate matter. Some fibrous material in the aluminum sludge appears to be organic.

Volumes I and II of this study were published as Research Reports No. 16 and 24 in the Canada-Ontario Agreement series.

Authors: Various from the Departments of Land Resource Science and Microbiology, University of Guelph, Guelph, Ontario.

Project No. 72-5-17

282 p., tables, figures.

RESEARCH REPORT NO. 46

COMPUTER-AIDED PLANNING OF REGIONAL SLUDGE DISPOSAL SYSTEMS

B & P Silveston, Engineers
and
The Canadian Federation of Mayors and Municipalities

During the 1950's and 60's, with the impetus of the Ontario Water Resources Commission, numerous sewage treatment plants were built throughout Canada. The result of this, as time went by, was that the problem of sludge disposal became one of concern for many municipalities. Traditionally, in Canada, the disposal of solid wastes and sewage sludge is the responsibility of each municipality, industry or individual. However, the growth of urban areas, often by amalgamation of many areas, left a number of small plants and dump sites to be operated by one political body.

This, of course, resulted in a two-fold problem: the first, of coordinating the various facilities and, the second, the matter of planning the possible interconnection, enlargements or deletions in the expansion of a growing area.

In addition to the above, public concern about pollution hazards has mounted, with the result that casual dumping is no longer acceptable. This has forced many municipalities to re-examine disposal practices.

Political considerations and spiraling costs have dictated a need for detailed and comprehensive planning in the disposal of waste products. The ready availability of computers now makes this planning possible. The purpose of this report is to show how a proper program with the aid of computers can be of great help in making planning decisions.

The method described in this manual is properly termed "a computer-aided planning method". By no means is it a method whereby one presses a button and out spews reams of paper detailing a regional plan for sewage sludge disposal. The concept is an interactive one. The engineer-planner assembles information on the disposal problem which the

computer manipulates to serve up one or more answers. In turn, these cause new questions to be asked, the computer yields new answers, and so on. From this process of question and answer eventually emerges a comprehensive plan for sludge disposal.

This manual is intended to serve a number of purposes. First of all, it is a training manual which introduces potential users to the concepts of computer-aided planning, the models for sludge disposal that are imbedded in the computer programs, and the information which must be developed in order to use the programs. The manual is also a source book for setting up a data collection program to be used with computer-aided planning. It contains the coding which transforms the data into the proper form for processing by a computer. Thirdly, the manual provides detailed information on the structure of the computer program, so that it can be modified for special purposes or expanded to handle different planning problems such as refuse disposal. Only a minor attempt has been made to indicate the chronology of the project, the sources of information used and the problems tackled during its active life. In a very real sense, the User's Manual is the final product of work undertaken in the project.

A general purpose computer program applicable to the optimization of regional sludge disposal systems is described. The model upon which the computer program is built is a network of transport routes connecting nodes which represent sources of sewage sludge, intermediate facilities for processing or the temporary storage of sludge (such as vacuum filters or lagoons), and dead-end facilities for ultimate disposal (such as landfill or land spreading sites). Since the spreading of sludge on land is an alternative which will usually be considered, and as this is permitted only within certain portions of the year, the model permits intermediate facilities to be designated for winter storage of sludge which would otherwise be distributed to dead-end facilities which are seasonally restricted.

The engineer-planner within the computer-aided method retains his essential position, but the nature of the work he does is changed by the technique. In addition to data collection, it is his responsibility to postulate sets of facilities (without specifying their size, but only the upper limits on size) which are to be considered within the computer

program. Using given transport costs per unit volume of sludge (as functions of travel time) and given functions of facility cost versus size, which must be supplied by the engineer-planner, the computer program finds what combinations of facilities meet the disposal requirements at least cost and how sludge should be distributed from the sources to these facilities. The computer program actually prints out lists of the near optimal solutions to the planning problem. It then becomes the responsibility of the engineer-planner to analyse these solutions and develop, through the use of case studies, a solution which gives low cost sludge disposal and also satisfies aesthetic social and political considerations as well.

To test the performance of the computer program, the Regional Municipality of Niagara supplied cost data, lists of potential disposal facilities and their locations, and data on sludge productions at the various waste treatment plants located within their boundaries. A detailed study of sludge disposal in the Regional Municipality was not undertaken; however, runs were made to examine the sensitivity of the computer-generated solutions to assumptions in the cost data. Runs were made also for projected sludge production in 1980 and 1990. This yielded a picture of the development of the sludge disposal system with time. It is perhaps this aspect which may be most valuable to the engineer-planner, since long term studies are hardly conceivable without computer assistance.

A second computer program was developed in the course of this project to plan an optimal transport system to move from sludge to sources to the chosen disposal facilities. Given depot locations for the trucking fleet, the carrying capacity of trucks, and an operating factor, the computer program generates the least cost schedule of pickups for the sludge disposal network. Allowing depot locations and truck sizes to vary, a case study approach can be used to find an optimal transport system for sludge. Conditions of this contract only permitted development of the basic computer program for this task. Although this program has been tested on a hypothetical example, application to a real system will probably be necessary before it can be released for general use. Some polishing of the

program to simplify data input and improve the computer printout is also required.

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Project No. 73-5-8

409 p., figures, tables

RESEARCH REPORT NO. 50

ANAEROBIC DIGESTION OF LIME SEWAGE SLUDGE

Ontario Ministry of Environment.

At the end of 1975, Ontario had phosphorus removal facilities in operation at more than 200 wastewater treatment plants. The first full scale phosphorus removal facility in operation in Ontario was at the Newmarket WPCP. Here, hydrated lime is added to the raw sewage of the two million Imperial gallon per day conventional activated sludge process, effecting an average of 80% phosphorus removal efficiency. Sludge treatment is provided by a two-stage anaerobic digester with ultimate disposal onto neighbouring farm fields.

Trouble developed in the operation of the digester when gas production dropped markedly resulting in a shutdown. Early in 1972 when this happened, laboratory investigations had indicated that anaerobic digestion of the lime sludge should be possible. Therefore, the activity under this study was directed toward evaluating the operation of the anaerobic digestion process for the treatment of lime sludge.

At present there is a lack of detailed knowledge concerning the actual process involved in digestion and, consequently, also concerning the cause of digester failure. However, over the years "normal" operation parameters have been established, and "causes" of digester failure have been documented.

It is shown that sludge produced by lime addition to a conventional activated sludge sewage treatment facility may be digested in a two-stage anaerobic digester. Drastic variation in feed concentration must be avoided.

Author: S.A. Black, Pollution Control Branch, Ontario Ministry of Environment, 135 St. Clair Avenue West, Toronto, Ontario.

Project No. 71-1-18

17 p., figure, table

RESEARCH REPORT NO. 51

HEAVY METALS IN AGRICULTURAL LANDS RECEIVING CHEMICAL SEWAGE SLUDGES

VOLUME IV

Analytical Methods for Sewage Sludge Analysis
Institute for Environmental Studies
University of Toronto

The objective of this study was to review and develop analytical methods for sewage sludge analysis. It had been agreed in earlier work on this project that knowledge of the form of metals in waste and environmental samples is of great importance. This has led to emphasis, during this stage of the study, on the development of simple equipment and methods to initiate metal speciation studies.

Procedures developed in last year's report* and labelled as "provisional" were studied in depth. The mercury method is now acceptable as recorded. The As/Se procedure has been modified as a result of further investigation.

Some environmentally important metals, e.g., silver, tin and vanadium, are not readily analyzed in sludges by conventional flame atomic absorption. Nonflame atomic absorption methods were developed for silver and vanadium. The hydride method for tin was extensively investigated, but further work will have to be done before satisfactory results can be reported.

It is emphasized that obtaining total heavy metal data on wastes and environmental samples does not necessarily allow a meaningful interpretation of the environmental impact of the metals. This is patently evident in published studies on lead and mercury.

Work at the authors' laboratory, and in those of other researchers, suggests that combining atomic absorption as a detector with powerful separational techniques is a relatively simple and inexpensive method of doing metal speciation work.

Metal speciation studies are much more difficult than studies involving total heavy metals. It is demonstrated that using atomic

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* Research Report No. 30.

absorption spectroscopy as a detector does not guarantee a quick solution to metal speciation problems. The opinion is expressed that atomic absorption spectroscopy will, in time, make as great a contribution to metal speciation studies as it did in the past decade to the routine analysis of total metals.

It is demonstrated that sludges can be dry-ashed at 450°C without fear of loss of cadmium, lead or appreciable zinc. When aluminum is to be determined, dry-ashing should not be used. Data also make it clear that incineration at temperatures usually employed will release large amounts of arsenic, cadmium, lead, mercury and zinc.

Author: Jon C. Van Loon, Institute for Environmental Studies, University of Toronto, Toronto, Ontario.

Project No. 72-5-3

33 p., figures, tables

RESEARCH REPORT NO. 52

EXAMINATION OF SEWAGE SLUDGE FOR ENTEROVIRUSES

VOLUME II

Ontario Ministry of Health

The main objective of this study was to collect sewage sludge from selected pollution control plants in Ontario at regular intervals, and to test the specimens collected for the presence of pathogenic viruses by cell culture inoculation, electron microscopy and other related methods. A related objective was to determine whether faecally excreted viruses survive for prolonged periods in sludge destined for land application.

In studying methodology, the decontaminating efficacy of chloroform as a safe decontaminant in processing sewage extracts for enterovirus isolation was determined. In hundreds of tests using the chloroform treatment no difficulty was experienced due to bacterial contamination.

Studies were carried out on the efficiency of virus isolation procedures. It was possible to recover 100 to 10,000 $TCID_{50}$ of added virus from 10 ml without loss, showing that the extraction procedure is efficient. Results with sludge also appeared to be satisfactory if allowance was made for the initial virus loss. During the three years, 1973-1975, over 13000 specimens were examined. These included water, raw sewage, raw sludge and digested sludges. In the case of sludges, eleven percent of raw sludges and seven percent of digested sludges yielded viruses, but there were considerably more virus isolations from digested sludges in 1975. Viruses were isolated from 21% of sewage influents examined (506). During the three years, 18 polioviruses belonging to all three types were isolated.

All the nonpolio enteroviruses identified so far have been found to belong to the coxsackie B group with one exception, which was a coxsackie A9 virus.

The report concludes guardedly that spreading sludge poses only a low-level health hazard. This is qualified by adding that virus

prevalence in the communities was low, and that practical detection methods are not available for the important agents responsible for hepatitis and gastroenteritis.

Surveillance should be continued and improvement of methodology of both sample collection and virus detection should receive priority. It is emphasized that any sewage related material leaving the treatment plants should be treated adequately to ensure virological safety.

Author: T.P. Subrahmanyan, Laboratory Services Branch,
Ontario Ministry of Health, Toronto, Ontario.

Project No. 72-5-1

35 p., figure, tables

RESEARCH REPORT NO. 53

LAND APPLICATION OF DIGESTED SLUDGE UNDER ADVERSE CONDITIONS

Regional Municipality of Niagara

Land disposal of municipal sewage sludge, without further treatment and under adverse conditions, was considered in this report. Because of its fertilizer and soil conditioning qualities, and of its relatively low cost, the digested sewage sludge is usually applied to the land by tank truck.

Problems are associated with this practice of land application during the autumn and spring months. Soils are soft and wet because of rain and the thawing of snow, and conventional sludge hauling vehicles are unable to drive over fields without becoming mired or causing excessive rutting and compaction of the soil. Consequently, sludge storage facilities are required. Storage can be provided in the digesters, but this is limited, and introduces many other problems.

In this study the assumption was made that the fertilizer and soil conditioning values of digested sludge are best used in field crops, as opposed to incineration or landfilling.

The objectives of the study were:

1) to determine the suitability of various types of tracked vehicles and low pressure wheeled vehicles to the spreading of sludge on wet fields;
2) to determine the effect of using injectors in applying sludge to the land, especially to frozen ground;
3) to determine the effect on crops of the various means of application;
4) to evaluate the effectiveness of sludge spraying as a means of sludge application to land.

The conclusions reached were rather negative. None of the vehicles or methods investigated proved to be ideally suitable and effective. The bulldozer type vehicle was too slow and heavy, causing exces-

sive damage to the topsoil and turf. The front-end loader was too cumbersome, and also caused excessive field damage. Spreading was too slow with the all-terrain vehicle, and it also caused field damage. The sludge injector caused the least field damage, but frequently clogged, and was ineffective in hard soil. The tank truck also caused minimal field damage, but became easily mired, in which case it then caused excessive field damage. Sludge spraying was the most effective system in mild and calm conditions and with well-screened sludge.

The opinion is expressed that there is perhaps no single simple solution, and that any choice made for a particular situation at best will be a compromise between effective sludge spreading and minimal difficulties.

Author: Pollution Control Division, Public Works Department,
Regional Municipality of Niagara, Ontario.

Project No. 73-5-9

59 p., figures, tables

RESEARCH REPORT NO. 58

AEROBIC DIGESTION OF ORGANIC SLUDGES CONTAINING INORGANIC PHOSPHORUS PRECIPITATES VOLUME II*

Institute for Environmental Studies
University of Toronto

Lime treatment of raw sewage has been used in many wastewater treatment plants to assist phosphorus removal. It has also assisted the clarification. However, until this study was made, little was known of the aerobic digestion of the sludges resulting from lime treatment.

Laboratory experiments were carried out at 20°C in completely mixed digestion units on sludges collected from a municipal wastewater treatment plant in Metropolitan Toronto. Tests were carried out simultaneously on lime-primary sludges (precipitated with $Ca(OH)_2$) and primary sludges with no chemical addition. Batch digestion and semicontinuous loading experiments were made. Lime-primary sludges from raw sewage precipitated with different lime dosages (140-600 mg/l) were studied at pH values of 9-12. For comparative purposes, all sludges studied had initially a similar volatile solids content. Digester detention time was varied from seven to fifteen days to investigate the effect of this parameter on aerobic digestion of the sludges.

As a result of the study it was concluded:

1. Aerobic digestion of lime-primary sludges is feasible even for sludges with initial pH as high as 12.
2. In both batch and semicontinuous loading, the pH of the sludges decreased from an initial value of 9-12 to an average of 8.5, remaining constant at this level during digestion regardless of digestion time.
3. The total alkalinity of the lime-primary sludge did not decrease as a result of aerobic digestion.
4. Lime-primary sludges having initial pH in the range 9-10 showed a higher degree of organic solids decomposition than primary

*Phase I of this study was reported in Research Report No. 3.

sludges. For all sludges studied, the organic solids decomposition was a function of digestion time.

5. The kinetics of organic solids decomposition was affected by the alkalinity, or calcium ion contents, during aerobic digestion of lime-primary sludges.
6. Oxygen uptake rate of the sludges normally decreased with increased digestion time.
7. The nitrification process which usually accompanies aerobic digestion of sludges was inhibited in digesters treating lime-primary sludges with high lime dosages.
8. Release of phosphorus, nitrogen and organic carbon during digestion was negligent, and supernatant from the digested sludges had a low nutrient content.
9. Aerobically digested lime-primary sludges had excellent dewatering characteristics, producing relatively clear supernatant as compared to primary sludges.
10. Detention periods of at least fifteen days were required in the semi-continuous loading experiments treating lime-primary sludges at 20°C, especially when sludges having initial pH values in the higher range were treated.

Project No. 72-5-4

Authors: J. Ganczarczyk and M.F.D. Hamoda,
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81 p., figures, tables

RESEARCH REPORT NO. 59

FULL SCALE STUDIES ON THE THERMOPHILIC ANAEROBIC DIGESTION PROCESS

Ontario Ministry of the Environment

While the major objective in the design and operation of water pollution control plants is the production of high quality effluents through the removal of organic pollutants, attention must be paid to the considerable quantities of sludge produced in achieving this goal. Sludge requires some form of pretreatment prior to disposal. While numerous research studies have been conducted to determine potential application of various unit processes and operations to sludge treatment, higher capital and operating costs are invariably associated with other methods of sludge treatment than anaerobic digestion. As a result, conventional mesophilic anaerobic digestion continues to be used, and little research work has been conducted to determine the maximum capabilities of anaerobic digestion systems. It was thought that, through the use of thermophilic digestion, it may be possible to increase capabilities of existing anaerobic digesters, and to reduce capital costs associated with sludge stabilization in proposed treatment facilities. Most of the research studies conducted on thermophilic digestion have been on a laboratory scale, with only two full scale studies reported in the literature, both over two decades ago.

A plant scale thermophilic anaerobic digestion study was conducted to assess the feasibility and performance, and to provide economic guidelines for the process as compared with conventional mesophilic systems.

The study was conducted in four distinct phases: the first three at specific applied digester loadings, with the fourth studying the effect of shock loadings. A full scale mesophilic digestion system, operating on the same raw sludge feed, was used as a comparison.

At a conventional digester loading of 0.8 lb VS-ft^{-3}-day^{-1} (1.3 km-m^{-3}-d^{-1}) and retention time of 26 days, the thermophilic process achieved an overall performance similar to the mesophilic control system at the same loadings and using the same raw feed sludge.

At higher applied loadings (2.5 times higher) and retention time of 7.5 days, the thermophilic digester continued to provide good overall performance.

The chemical characteristics of the final digested mesophilic and thermophilic sludges appeared similar. Supernatant liquor from the thermophilic operation contained approximately twice the solids concentration of the mesophilic liquor.

The specific gas production was similar for both processes, as was the quality of the gas produced, both averaging 65% methane, the balance being carbon dioxide.

Thermophilic digestion was an order of magnitude more effective than mesophilic digestion in reducing the number of organisms capable of growth at 35°C.

Thermophilic primary digester pH levels were half a unit higher than those seen in the mesophilic system, while volatile acids concentrations were 25 times greater. Other digester operating indices were similar in the two systems.

Neither digestion process produced sufficient digester gas to satisfy all plant heating demands for winter operation.

The immediate practical application of the thermophilic process would appear to be the conversion of existing overloaded mesophilic units where digestion performance is poor. The improved digestion associated with the conversion would also likely include higher gas production rates than previously seen, thereby rendering the thermophilic process economically attractive.

It is recommended that thermophilic anaerobic digestion should be considered as an alternative to the mesophilic process in future design and construction in view of the likely capital cost savings associated with the former process.

Further research should be conducted upon the thermophilic digestion process to establish the upper loading limits.

Investigation into the basic microbiology of the organisms responsible for digestion, and definition of the rate-limiting factor, should be conducted with a view of increasing solids destruction performances and specific gas production rates, allowing enhancement of

process economics and the possible creation of a real, supplemental energy source.

Project No. 73-1-29

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79 p., figures, tables

RESEARCH REPORT NO. 60

LAND DISPOSAL OF SEWAGE SLUDGE

VOLUME IV*

University of Guelph

This section of the overall study of land disposal of sewage sludge was designed to determine rates of sewage sludge which may be safely applied to certain slopes at specified times of the year. The report discusses the results from the third year of field runoff studies with fall, winter and spring application of fluid sewage sludge on land cropped with grain corn. Runoff of water, soil, nutrients and metals have been measured.

The report also covers field rate and source studies with three sludges resulting from treatment of sewage with calcium hydroxide, ferric chloride and aluminum sulphate for phosphorus removal.

One experiment involves surface sludge applications on a loam soil on which bromegrass is grown, and three trials involve corn on a loam, a sandy loam and a clay loam soil.

In one greenhouse experiment nine fluid sewage sludges, selected for their high metal content, were applied to a soil previously adjusted to two pH levels. Five crops of ryegrass have been grown with sludges added before each crop.

Crop growth and nutrient and metal uptake have been studied in the trials along with micropedological studies of the soils. The sludges and field-grown crops have been monitored for pathogenic organisms.

Field experiments and laboratory studies have been used to estimate the nitrogen availability from sludges and the rates of volatilization of nitrogen from surface applied sludge in the field.

A greenhouse experiment has also been run on a group of soils varying in metal content. The soils were extracted with various chemicals in an effort to find suitable extractants for plant available cadmium, copper, nickel, lead and zinc.

Total runoff in 1975 was similar to 1973 and 1974, as were nitrogen, phosphorus and metal losses. Metal losses were small, and

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*Volumes I, II and II have been published as Research Reports No. 16, 24 and 35 respectively.

mostly associated with summer losses of soil solids. Sludge application has no effect on total runoff volume.

In the field rate and source studies the bromegrass had slightly higher yield with sludge than with ammonium nitrate. At low rates of application the calcium sludge tended to produce lower yields and higher yields at higher rates of application than the other sludges, a trend which had been apparent in 1974. Corn yields were little affected by nitrogen or sludge in 1975.

The sludges markedly increased sodium bicarbonate-extractable "plant available" soil phosphorus, with the calcium sludge being much more effective than the other sludges. Phosphorus concentrations in the crops were high and unaffected by treatment.

Cadmium content of both grass and corn stover was increased by sludge application, the effect being highest with the sludge supplying the most cadmium. Nickel, chromium and copper were increased in some plant tissues at some sites, but the effects were not consistent. Zinc concentration increased in bromegrass, corn grain, and at one site in corn stover. Molybdenum in plant tissue appeared to increase with sludge application.

In the greenhouse study, increased rates of sludge applied at one time increased the concentrations of metals in ryegrass. Repeated cycles of sludge application and cropping did not increase metal concentrations in the ryegrass from one crop to the next (up to the fifth crop) at any of the rates studied.

Several extractants could be used to predict cadmium, nickel and zinc concentrations in Swiss chard, predictions being improved in most cases where pH, clay content, organic matter and cation exchange capacity were also measured. Nitrilotriacetic acid is probably the most universally acceptable extractant for all three of these metals on the group of soils studied.

Electron microprobe, scanning electron microscope and light microscope investigations lead to the conclusion that surface accumulation in the greenhouse soils were a mixture of salt evaporites and microorganisms.

Salmonella species were detected during the 1975 season in sludges (11 of 15 samples) and corn (4 of 24 plot samples). Salmonella species were not detected in the runoff waters (132 samples) or in the grass samples (36 plot samples).

During the longer period, May 1973 to March 1975, salmonella species were detected in 20 of 54 samples of sludge, one of 484 samples of runoff waters, two of 96 samples of grass, and four of 24 samples of corn.

Project No. 72-5-17

Authors: T.E. Bates, E.G. Beauchamp, R.A. Johnston, J.W. Ketcheson, R. Protz and Y.K. Soon, Department of Land Resource Science, University of Guelph, Guelph, Ontario N1G 2W1

317 p., figures, tables

RESEARCH REPORT NO. 67

CHEMICAL SEWAGE SLUDGE DISPOSAL ON LAND (LYSIMETER STUDIES) VOLUME I

Environmental Protection Service
Environment Canada

Significance

A recent survey of sludge disposal practices in Ontario indicated substantial increases in both sludge volumes and dry weight as a result of chemical additions to wastewater for phosphorus removal. The chemicals most commonly used for this purpose are alum, ferric chloride or lime.

Little information is available concerning the environmental impact of chemical sludges in either liquid (fluid) or dry forms when applied to a wide variety of agricultural soils producing many different crops. Of particular concern to public health authorities and regulatory agencies are the potentially deleterious effects on soils, groundwater, and plants of the numerous toxic substances such as heavy metals which are increasingly concentrated in wastewater sludges as effluent regulations become more stringent.

The long term risks of applying chemical sludges to farmland must be assessed.

Program Outline

To provide some of this information, a lysimeter project was initiated in October, 1972 by Environment Canada at the Wastewater Technology Centre, Burlington.

Two separate lysimeter experiments were designed to determine long term effects on soils, plants, and leachate of applying:

1) Fluid digested chemical sludges (alum, iron, and lime) to two medium textured soils growing orchard grass;
2) Air-dried digested chemical sludges to clay and sand, growing wheat crops.

The major objective of these ongoing studies was to determine the maximum sludge rates which can be applied to various agricultural soils growing either forage or edible crops (wheat) without causing deleterious effects to:

- soil productivity (crop yield);
- plant quality (heavy metal toxicity); and
- groundwater quality (for drinking or irrigation water).

This report summarizes results of the fluid sludge lysimeter experiment to the end of 1974.

Subsequent volumes in this series will update information on these ongoing studies.

Methodology

The fluid sludge experiment was designed as a randomized block of 66 lysimeters using three replications of two soil types, eleven fertility treatments consisting of three sludge types, three sludge loading rates and two controls (with and without NPK commercial fertilizer). The sludge consistency (fluid), soil types (loamy sand and silt loam), and agricultural crop (orchard grass) were chosen to enable subsequent comparison with field studies carried out by the University of Guelph. Sludge types were chosen to include the three most common chemicals used for phosphorus removal (alum, iron and lime). Sludge loading rates (kg TKN/ha) were chosen to closely approximate the soluble nitrogen requirement for crop production at the lowest application rate, with the medium and high rates double and triple the low rate.

Fluid sludge was applied three times in 1973 and four in 1974, each time at 100, 200 and 300 kg TKN/ha, resulting in cumulative loading by 1974 of 2,100 kg TKN/ha at the highest rates.

Crop yields were determined and the plant tissue was analyzed for nitrogen (N), phosphorus ((P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), manganese (Mn), iron (Fe), aluminun (Al), zinc (Zn), copper (Cu), nickel (Ni), cadmium (Cd), chromium (Cr), and lead (Pb).

Leachate was collected periodically to represent different periods of the year. Leachate quality was monitored for pH, conductivity and chemically analyzed for nitrate nitrogen (NO_3-N),

ammonium nitrogen (NH_4-N), nitrite nitrogen (NO_2-N), total Kjeldahl nitrogen (TKN), chloride (Cl), sulphate (SO_4), total carbon (TC), total organic carbon (TOC) as well as P, K, Ca, Mg, Na, Fe, Al, Mn, Zn, Cu, Ni, Cr, Cd, and Pb.

Samples of sludge, soil and leachate were collected for microbial analysis. Sludge amended soil samples (2 cm cores) to a depth of 61 cm were taken in April 1974 for microbial analysis. These cores were subsectioned into 2.5, 7.5, 15.0, 25.0, 37.5, and 60.0 cm depth fractions for the study of microbial vertical movement in the soils.

Conclusions

1) Orchard grass dry matter yields during the second year (1974) exceeded 1973 yields. Yields increased with increasing sludge application rates to both soils for both years. Iron sludge at the highest application rate produced the highest yield. The lowest yields from sludge treatments were obtained from 1973 alum sludge (Point Edwards), containing high lipid and petroleum hydrocarbon concentrations. During 1974, yields from a normal (low lipid) alum sludge (Tillsonburg) were comparable to other sludge sources.
2) Concentrations in plant tissue of N, Na, Cu, and Zn increased with increasing rates of sludge application. Concentrations of K and Mn decreased with increasing sludge rates. Calcium, Mg, Ni, Cr, Pb, and Cd concentrations were generally not affected by sludge type or application rate. The metallic ions, Al and Fe, used for P removal, did increase the concentration of these two elements in plant tissue compared to the lime and NPK control treatments.
3) Potassium concentrations in plants grown during 1974 were deficient ($<1.0\%$ K) at the higher sludge loading rates possibly limiting crop yields. Concentrations of the plant nutrients, N, P, Ca, and Mg as well as the heavy metals Cu, Zn, Ni, Pb, Cr, and Cd, were within the normal range.
4) The cumulative (1973 to 1974) plant uptake of N, P, K, Al, Fe, Ca, Zn, Cu, Ni, Cr, Pb, and Cd was greatest at the high rate of iron sludge applied to silt loam. The lowest uptakes occurred at the low rate of alum sludge applied to loamy sand.

5) Nitrate-N, Ca, and Cl concentrations in leachate from both soils were high during the first (1973) growing season, declined during the dormant period (1973 to 1974) and remained low during the second (1974) growing season. Concentrations of NO_3-N during the dormant and the following growing season were less than the drinking water (Canada, 1969) maximum allowable concentrations (10 mg/L) for all treatments. Total organic carbon (TOC) cncentrations did not exceed 15 mg/L in 1973 but increased substantially during the 1974 growing season. Total phosphorus concentrations in leachate were generally below 0.2 mg/L.

6) Concentrations of Ca, Mg, Fe, Cu, and Zn in leachate were within the acceptable drinking water limits while chloride, Na, Mn, Ni, Cr, Pb, and Cd concentrations were within irrigation water limits.

7) Cumulative (1973 to 1974) leachate losses of P, K, Al, Fe, Zn, Cu, Ni, Cr, Pb, and Cd were negligible. Leachate N and Ca losses were higher from loamy sand than silt loam.

8) Leachate heterotrophic bacteria identified during 1973 and 1974 were of soil origin ranging from 0.1 to 5.5×10^6 per ml. The sludge microorganisms were retained in the top (15 cm) soil layer, although no coliform bacteria were observed below 7.5 cm.

9) The highest calculated accumulations of N, P, and Al and depletion of K from both soils occurred at the high rate of alum sludge. The highest accumulation of Fe, Zn, Cu, Cr, Pb, and Cd occurred at the high rate of iron sludge application. The high rates of alum, iron and lime sludge applications resulted in the highest accumulation of Al, Fe, and Ca, respectively, in both soils. The long term effects of heavy metal accumulations in soils at current rates of application remain to be determined.

10) Cadmium is the heavy metal of greatest concern in these experiments. All sludge types used will double the initial soil Cd content in less than one year at the highest application rate. The relationship between cumulative total and plant available Cd loadings and actual Cd concentrations in plant tissue remains to be determined.

Recommendations

1) The contamination of groundwater by NO_3-N in leachate must be avoided by limiting the nitrogen loading (as a sludge or commercial fertilizer) to the nitrogen requirement of the specific crop being grown.
2) A blanket K application of 200 kg K/ha/yr is recommended for all fertility treatments in order to maintain an available N/K ratio of approximately 2:1, and thus avoid future plant K deficiencies.
3) This study should continue at the present annual rates of sludge application until either plant toxicity, depressed crop yield or leachate contamination are observed and evaluated.
4) After one or more of the adverse effects listed in recommendation three have occurred, the lysimeters should be depth sampled to determine heavy metal vertical migration. Sludge amended soil actual material balances should be compared with calculated balances based on leachate and plant uptake loss.

Project No. 72-3-6

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98 p., figures, tables

RESEARCH REPORT NO. 69

REUSE OF WASTE SO_2 AND PHOSPHATE SEWAGE SLUDGES BY SOLIDIFICATION WITH LIME AND FLY ASH

Acres Consulting Services Limited

In September, 1972, Acres Consulting Services Limited was awarded a contract to carry out a research project on the solidification of phosphate-bearing sewage sludge.

The objectives of the project were to determine if phosphate can be held in an inert form within a cementing matrix of fly ash, lime, industrial waste sulphuric acid, and sewage sludge, and whether the resultant material would have adequate strength to serve as a load-bearing fill. This report summarizes the work done at Acres to accomplish these objectives.

The laboratory phase of this research work indicated the feasibility of mixing sewage sludge with certain other waste ingredients to form a self-setting mix which consolidates well and is capable of long-term retention of the phosphates in a cementing matrix. The mix ingredients consisted of fly ash and SO_2 sludges from coal burning thermal power plants, and spent acids from industrial processes. Hence, several waste disposal problems may be solved simultaneously. The only commercial commodity required for the process is lime which is easily obtainable and relatively inexpensive. The sludge/fly ash mixture can be produced either as a compactible mix or a liquid slurry. The compactible mix is an excellent base material for road and parking lot construction. The liquid slurry could be piped to landfill sites where it should set-up and gain sufficient strength so that these areas could be used as building sites.

Further laboratory research is required to determine the effect of changing the proportions of the various ingredients on long-term strength gains, leaching of phosphates and survival of pathogens.

The following conclusions were given in the report:

- It is possible to produce a cementing matrix which is composed essentially of waste materials.
- This matrix, when mixed with as much as 6% dry phosphate-bearing sewage sludge, will keep the phosphates in an inert form. The resultant material will have adequate strength for highly loaded (>450 psi) landfill. Where the resultant material is to be used as lightly loaded landfill (<150 psi), a greater quantity of dry phosphate-bearing sewage sludge can be contained within the cementing matrix than for highly loaded landfill.
- Total phosphate leached during 15 days from a variety of compacted mixtures containing sewage sludge never exceeded 0.01% of the phosphate input to the mixture.

Project No. 72-5-2

Author: Acres Consulting Services Ltd., Niagara Falls, Ontario.

22 p., tables, figures

RESEARCH REPORT NO. 70

REPORT OF THE LAND DISPOSAL OF SLUDGE SUBCOMMITTEE PROJECTS CONDUCTED 1971-1978

A significant concern that was identified by the Technical Committee of the Canada-Ontario Agreement on Great Lakes Water Quality is the disposal of municipal sludges produced from the chemical treatment of sewage for phosphorus removal. In addition, the desire to utilize this nutrient-rich material on agricultural lands, and the awareness of the possible presence of significant concentrations of toxic metals and other potentially harmful substances in sludges, has resulted in a need to conduct intensive investigation in the area of sludge disposal. The Land Disposal of Sludge Subcommittee was formed to develop a strategy for research activities, to commend and to oversee projects relating to sludge disposal, as well as to provide advice on questions referred to it.

Research Strategy of the Subcommittee

Through support of research funding provided under the Canada-Ontario Agreement, considerable research work into land disposal of sludges has been carried out in-house and through contracts.

In Ontario, a majority of the small to medium-sized pollution control plants dispose of processed sludge through application onto agricultural land. This is about 34% of all sludge produced. While sludges have been disposed of on land for many years, concerns have mainly been associated with odours. These, as well as aesthetic concerns, have resulted in political objections and subsequent local restrictions. It is only in recent years that questions have arisen concerning the potential environmental problems associated with this method of disposal. The introduction of chemical sludges from phosphorus removal facilities has raised further questions concerning this practice.

The application of sewage sludges onto agricultural lands under the proper conditions is not only economical but can result in fertilization and improve soil properties for greater uses. The widely

accepted concept of recycling is also being effected by this practice. Canada-Ontario Agreement supported research has provided a significant data base to enable the Ontario Ministry of the Environment and the Ministry of Agriculture and Food to develop guidelines for the utilization of processed sewage sludges on some agricultural lands. The guidelines will be kept under continual review and will be updated as investigations continue.

This report summarizes the research projects and conducted by the Subcommittee between 1971 and 1978.

RESEARCH REPORT NO. 71

DEVELOPMENT OF AN EFFICIENT SAMPLING STRATEGY TO CHARACTERIZE DIGESTED SLUDGES

Environmental Protection Service
Environment Canada

This investigation was performed to estimate the degree of variability in the physical-chemical characteristics of liquid sludge discharged from anaerobic digesters. Constituent concentrations measured included: TKN, NH_3-N, TP, Fe, Ni, Cu, Zn, Pb, Cd, Al, TOC, TDS, TS, VS. The purpose of these measurements was to aid in the design of efficient sampling programs to monitor process outputs at water pollution control plants. Observations were taken at five Ontario water pollution control plants; each used the conventional activated sludge process. Three plants disposed of liquid sludge by truck haulage to farmland; two plants semi-continuously pumped liquid digested sludge to dewatering devices. The largest plant treated an average of 4.7 MIGD (21,400 $m^3 \cdot day^{-1}$) of raw sewage. Sampling programs varied from two-week intervals to five-month intervals. Plant records (TS, VS) for two-year intervals were examined for two of the plants to estimate the characteristics of long term variations, and to obtain an appropriate sampling frequency. The following conclusions have been made:

1) The greatest contribution to digested sludge variability occurred within a single operating day for batch and semi-continuous withdrawal modes. Variability between days was masked by within day variability during two or three-week intervals. Sample handling and analytical testing were usually the smallest sources of variation.
2) A sample, composited from separate tank truck batches, can provide estimates of mean constituent concentrations within each batch with relative precisions in the range ±7 to ±55%: the greater precision is obtained with liquid phase constituents. A limited amount of data indicated that tank truck contents were relatively homogeneous after filling and transit to a disposal site.

3) Multiple batch loads of sludge hauled from a plant within the same sampling day must be monitored separately because there is a decrease in solid phase constituent concentrations in a sequence of batches. Rapid sludge withdrawal to tank trucks leads to potential channelling in the sludge blanket, and to reduced solids concentration.

4) Variability of liquid sludge sampled at plants which semi-continuously dewatered sludge was approximately one-third the loads. A composite sample, collected from the feed to a dewatering device during a sampling day, can provide estimates of mean constituent concentrations with relative precisions in the range ±5 to ±16%; the greater degree of precision is obtained with liquid phase constituents. The semi-continuous pumping from the secondary digester to a dewatering device accounted for a decrease in variability.

5) Total solids concentrations from two different plants' records were characterized by means which were constant during two-year intervals. Observations taken at one plant deviated randomly from the mean. Cbservations at the second plant were not random, but were autocorrelated in time owing to similar variations in the input to the system.

6) Digested sludge total solids concentrations can be efficiently monitored by using a randomly selected one-day sampling program every two weeks at plants practising batch or semi-continuous type sludge withdrawal. It is anticipated that other constituents may also be monitored in this way.

7) Significant changes in constituent concentrations other than total solids occurred during time intervals of several months, and correlation of heavy metal concentrations to total solids concentrations was an unreliable technique for prediction during similar intervals. Heavy metal concentrations were correlated with total solids concentrations during two or three-week time intervals.

8) Some constituents were more variable than others within the sludge at any single plant. Liquid phase constituents (NH_3-N, TDS)

were less variable than solid phase constituents (heavy metals, TKN, TP). NH_3-N can be estimated within approximately ±10% of the mean value at any time at either type of plant.

9) Short circuiting and dead space were observed in two primary digesters, and were considered the result of inefficient mixing. Mixing inefficiency can increase the heterogeneity of the end product, and decrease digestion efficiency.

10) The ammonia gas sensing electrode was found to be a rapid, precise method of determining NH_3-N concentrations in digested sludge at a plant site.

Recommendations

1) Since digested sludge composition varies from plant to plant, sampling must be conducted at individual plants to establish parameter concentrations and variability.

2) Digested sludge quality should be assessed using a frequency of one sampling day per two-week interval. The sampling day should be varied to eliminate daily bias.

3) At plants where sludges are discharged from the digester semi-continuously (i.e., dewatering plants), the sludge sample should be composed of at least three grab samples collected during the sampling day.

4) At plants where sludges are discharged from the digester batchwise (i.e., to tank trucks), each batch should be sampled and analyzed separately on the sampling day of the two-week interval. Each batch sample should be composed of at least three grab samples collected at the start, mid-point, and end of the feed cycle to the batch.

5) Slug inputs of heavy metals to water pollution control plants should be eliminated to reduce sludge variability.

6) Plant staff should be encouraged to keep complete records of digested sludge analyses and process stream flows. Where lack of facilities or manpower prohibits routine analyses at the plant, samples should be sent regularly to a central laboratory for

analysis. Process control charts should be used to aid the operating staff in keeping the process "in control".

7) Improved digester mixing methods should be investigated. Residence time distribution studies should be used periodically to determine mixing efficiencies of digesters. To obtain a uniformly digested sludge product, plants should be encouraged to use control strategies (e.g., pH control, solids recycle, uniform pumping schedules) to optimize digester performance. Improvement of present metering devices, such as raw sludge pumping meters and digester gas production meters, should be investigated.

8) The ammonia gas electrode can be considered for use where regulations require monitoring of ammonia in sludges (and effluent).

9) Projects to expand on the work described above should include:

   a. a study of the dynamics and improved mixing in anaerobic digestion;
   b. investigations leading to improved methods of sludge withdrawal from anaerobic digesters where sludges are currently discharged batchwise;
   c. examination of sludge solids data from other pollution control plants to further characterize the processes during lengthy time periods (more than one year);
   d. an estimation of the costs of sampling and analyses;
   e. an investigation of the procedures used by operators of tank truck disposal units to regulate the rate of discharge of sludge from tank trucks, and procedures allowing WPCP superintendents to advise operators on optimum disposal rates;
   f. an investigation of the consequences of solids fluctuations on chemical requirements at plants where sludges are dewatered.

Project No. 74-3-16

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124 p., figures, tables

RESEARCH REPORT NO. 72

SLUDGE DEWATERING DESIGN MANUAL

Environmental Protection Service
Environment Canada

Significance

The design of sludge treatment facilities has traditionally received much lower priority than the design of treatment systems for the liquid portion of the waste. This may have been due partially to the fact that until the liquid treatment facility was in operation there was no sludge, and to the fact that while liquid discharges were regulated by government standards, sludge disposal was not. It is still a common occurrence to find flow diagrams of waste treatment systems which end with an arrow and the caption "to sludge disposal", even though sludge handling and disposal costs may represent up to 50% of the total cost of waste treatment. In view of this, it is essential that sludge treatment design procedures generate data which will allow meaningful comparisons between various alternatives, and lead to the selection of the optimum system.

The potential impact of nutrient removal systems on the sludge handling requirements of conventional sewage treatment plants was recognized by the Canada-Ontario Agreement on Great Lakes Water Quality as one of the areas requiring further research. As a result a "Sludge Treatment Process Development Program" was initiated to characterize sludges, and to examine the control variables and scale-up techniques for several conventional dewatering installations. The work carried out under this project was instrumental in defining three areas of sludge dewatering where the information as presented in the literature was inadequate.

Most of the techniques and tests used to characterize sludges are reported in the literature, along with typical results for various types of sludges. In contrast, the interpretation and practical application of these tests as aids in the selection and design of a dewatering process is not well documented.

The design of dewatering installations should be based on data developed from either bench tests or pilot plant operation. The methodology whereby a designer can perform bench or pilot plant tests, interpret the data, and systematically develop specifications for dewatering equipment must be assembled from several literature sources for each process.

Since sludge dewatering equipment represents a major portion of the total cost of a sewage treatment plant, a preliminary estimation of this cost is essential. Developing a cost estimate on the basis of information obtained from the literature is a time consuming and frustrating task. Discrepancies between literature sources as to what components are included in a unit cost, such as capital investment, can easily result in cost estimates for the same system differing by a factor of 3 to 4.

Methodology

The preparation of a sludge dewatering design manual, by integrating data generated at the Wastewater Technology Centre with information assembled from the literature, was undertaken to satisfy the following objectives:

1) to identify meaningful sludge characteristics and discuss their significance and practical application to the design of various dewatering processes;
2) to outline a systematic process design proceeding from bench tests, to pilot plant operation to full scale design;
3) to develop a cost data base for sludge dewatering equipment which has common items included in each unit cost at a common time base.

The information presented in this manual is not intended for detailed plant design or cost analysis. The aim of this manual is to provide a methodology by which it is possible to estimate full scale dewatering requirements on the basis of experimental data, and develop an initial cost estimate for either comparing alternative systems or evaluating the economic feasibility of any specific system.

Results

Sludge characterization tests are identified, along with a discussion of each test and its potential use for design purposes.

A procedure for estimating the quantities of primary, waste activated and digested sludge, including the contribution of sludge from phosphorus removal processes, is presented.

Process design procedures for gravity thickening, dissolved air flotation, centrifugation, vacuum filtration and pressure filtration are presented. The procedure for each dewatering method includes a description of the unit process, a discussion of applicable bench or pilot plant tests, a suggested method of scale-up and an example problem.

Cost data (December, 1975) for the major pieces of equipment required for each process have been obtained from equipment suppliers and are reported as a function of an appropriate design parameter. Operating and maintenance costs collected from the literature are summarized. A methodology for developing cost estimates is presented and illustrated with example calculations.

Project No. 75-3-22

Authors: H.W. Campbell, R.J. Rush and R. Tew, Wastewater Technology Centre, Environmental Protection Service, Environment Canada, P.O. Box 5050, Burlington, Ontario L7R 4A6

133 p., figures, tables

RESEARCH REPORT NO. 73

LAND DISPOSAL OF SEWAGE SLUDGE

VOLUME V*

University of Guelph

This report discusses the results from the fourth year of field runoff studies with fall, winter and spring applied fluid sewage sludge on land cropped with grain corn. Nutrients and metals in runoff water were measured. The report also covers the fourth year of field rate and source studies with three sludges resulting from treatment of sewage with calcium hydroxide, ferric chloride, and aluminium sulphate for phosphorus removal. One experiment involves surface sludge applications on a loam soil on which bromegrass is grown, and two trials involve corn on a loam, and loamy sand. In one greenhouse experiment, six fluid sewage sludges, selected for their high metal content were applied to a soil previously adjusted to two pH levels. Eight crops of ryegrass have been grown with sludges added before each crop. Half of the treatments have received no sludge since the fifth crop. Crop growth and nutrient and metal uptake were studied in the above trials. Field experiments and laboratory studies have been used to estimate the nitrogen availability from sludges and the rates of volatilization of nitrogen from surface applied sludge in the field.

Runoff Studies

Runoff losses continued to be small with generally less than 1 kg N or 0.5 kg p/ha lost in one year. Rainfall and winter frost conditions appear to be more important than total precipitation in determining runoff losses.

Sludge application in winter does not create added hazards provided reasonable precautions are taken such as using the more level land, not applying sludge when the soil surface is covered with ice, and adhering to low application rates (1.5 cm depth or 200 kg N/ha or less).

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* Volumes I, II, III and IV have been published as Research Reports No. 16, 24, 35 and 60, respectively.

Field Rate and Source Studies

In the field rate and source studies, the bromegrass yielded slightly more with sludge than with ammonium nitrate. Corn yields were little affected by nitrogen or sludge in 1975 or 1976.

The sludges increased sodium bicarbonate-extractable ("plant available") soil phosphorus markedly, with the calcium sludge being much more effective than the other sludges. Phosphorus concentrations in the crops were high and little affected by treatment.

Cadmium contents of both grass and corn stover were increased by sludge application, the effect being greatest with the aluminun and iron sludges. Chromium was increased in some plant tissues at some sites, but the effects were not consistent. Copper and nickel concentrations in bromegrass and corn stover increased with high rates of sludge application. Zinc concentrations in bromegrass and corn stover were increased by high rates of sludges. Molybdenum in plant tissue appeared to increase with sludge application.

There appeared to be a slight increase in cadmium concentrations in bromegrass and corn stover from year to year on treatments receiving sewage sludge. In the case of zinc, a similar pattern was apparent only in corn stover from one site. Copper, nickel and chromium did not show increases in crop concentration from year to year.

Greenhouse Rate and Source Studies

In the greenhouse study, increased rates of sludge applied at one time increased the concentrations of metals in ryegrass with the exception of mercury and selenium. Repeated cycles of sludge application and cropping did not increase metal concentrations in the ryegrass from one crop to the next at any of the rates studied. One exception to this is zinc, which showed some increase from the fifth to the eighth crop. One application of sludge resulted in chromium and nickel concentrations in the eighth crop of ryegrass that were as high as in treatments receiving eight applications of the same amount of sludge. Cadmium, copper and zinc showed slightly reduced concentrations in later crops of ryegrass when sludge was stopped at the first or fifth crop.

The lack of build-up of most metals from one crop to the next where sludge was reapplied is quite unexpected and difficult to explain in most cases. The failure of chromium and nickel concentrations to decrease after sludge application ceased is also rather surprising.

Extraction of Metals from Soils

Aqua regia does not measure total metals in soils, and it is believed that it does not extract all the metals from soil. From this very brief study it appears that aqua regia extraction may be satisfactory as a measure of total metals added to soils in sewage sludges.

Nitrogen Studies

Soil NO_3^--N concentration in early April was higher where sludge was applied in previous years on the corn experiments, suggesting that residual sludge N was being mineralized and nitrified. The NO_3^--N concentration in the soil was usually lower under grass than under corn. Subsurface soil solutions contained relatively large quantities of NO_3^--N in early April where more N was applied than the crop required. This NO_3^--N is presumably available for leaching into the groundwater or drainage waters.

Nitrogen studies on abandoned runoff plots showed increased NO_3^--N concentrations in the soil on April 8 where sludge had been applied in the previous fall or winter over that present where sludge was applied in the previous springs but not in 1976. There was some build-up of NO_3^--N in the soil by June 22, and a corn yield response where 800 kg N/ha was applied in previous springs.

Contrary to expectations, determination of NH_4^+-N and NO_3^--N concentrations in sludge and soil layers following sludge application did not provide reliable information on NH_3 volatilization. The complicated meteorological approach used in 1975 appears to be more satisfactory.

Project No. 72-5-17

Authors: T.E. Bates, E.G. Beauchamp, A. Haq, J.W. Ketcheson, R. Protz and Y.K. Soon, Department of Land Resource Science, University of Guelph, Guelph, Ontario N1G 2W1

203 p., tables

RESEARCH REPORT NO. 74

Significance

The incineration of sewage sludge has increased in urban centres where land for the ultimate disposal of sewage sludge is restricted or is too distant to be used economically. Requirements for phosphorus removal from municipal wastewater treatment effluents have caused an increase in sludge volumes with considerably higher concentrations of phosphorus, its associated precipitant metals (e.g., Fe^{3+}, Al^{3+}, Ca^{2+}), and other coprecipitated metals which normally accumulate in the sludges. These elements survive the incineration process and appear in the incinerator ash. They will increase the weight of ash to be disposed of and may also cause long term environmental problems due to metal leaching from ash disposal sites.

These problems may possibly be alleviated by recovering the precipitant and recycling it within the treatment plant for phosphorus removal. Recovery costs may be partially offset by the lower quantity of fresh precipitant chemical that would be required.

Project Outline

During 1972, the Wastewater Technology Centre (WTC) of the Environmental Protection Service (EPS) initiated an experimental program aimed at developing and demonstrating technology for sludge incineration and precipitant recovery applicable to municipal wastewater treatment sludges. The objective of this program was twofold: (1) to investigate the recovery of lime and iron from chemical phosphorus removal sludges for the recycling of these chemicals in the phosphorus removal process, and (2) to evaluate multiple-hearth incineration of alum, iron and lime sludges.

As part of this research and development program, one of the first activities was to conduct an extensive review of the literature on sludge incineration and precipitant recovery processes. The information was published as a coded bibliography in Volume 1.*

*Volume I- Canada-Ontario Agreement Research Report No. 31

This report (Volume II) summarized bench scale investigations to determine the feasibility of recovering and recycling iron from sludge incinerator ash.

Specific objectives of this study were:

1. *to investigate at laboratory scale the leaching characteristics of high iron content incinerator ashes such as would result from a sewage treatment plant using iron salts for phosphorus removal;*
2. *to determine the required unit operations and design data to recover an iron salt from such an ash;*
3. *to evaluate the economics of such an iron recovery process; and*
4. *to assess the effectiveness of the recovered iron salt as a precipitant for phosphorus removal.*

Laboratory scale investigations undertaken to supply basic information pertaining to the incineration characteristics of various types of sewage sludges are the subject of a separate report - Volume III.*

A subsequent report in this series will describe pilot scale studies designed to optimize multiple-hearth furnace operating parameters for an iron-rich sludge (Hamilton Water Pollution Control Plant (WPCP)) and to establish scale-up relationships between pilot and full scale multiple-hearth sludge incinerators.

Methodology

The Hamilton WPCP does not have a conventional phosphorus removal system but has a sufficiently high influent iron concentration to give good phosphorus removal. Vacuum filtered sludge from this plant was burned at temperatures of 760°C (1 400°F), 816°C (1 500°F), 871°C (1 600°F) and 927°C (1 700°F) at a one-hour residence time in a multiple-hearth incinerator. The incinerator ash contained about 15 wt% iron and 5 wt% phosphorus. The ashes were tested for iron recovery using sulphuric acid, hydrochloric acid, nitric

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*Volume III- Canada-Ontario Agreement Research Report No. 75

acid, sodium hydroxide, calcium hydroxide and ammonium hydroxide plus ammonium sulphate.

The experimental equipment used to investigate leaching characteristics of the ash and recovery of the iron salt consisted of a constant temperature water bath with four, one-litre Erlenmeyer flasks each with motor and teflon paddle. Two hundred and three hundred g/L ash solutions were examined.

In the leaching characteristics experiments the variables studied were incineration temperature, time of leaching, leach solution (H_2SO_4, HCl, etc.), solution concentration and particle size of the ash.

In the iron salt recovery experiments the variables studied were precipitation temperature, time, acid concentration and initial precipitate (seed) concentration.

The phosphorus removal capability of the recovered iron salt was assessed using standard jar testing procedures.

Conclusions

1. Iron can be leached from iron-rich incinerator ash using either sulphuric or hydrochloric acid.

2. Iron can be precipitated from a sulphuric acid leachate by the addition of concentrated sulphuric acid.

3. The resulting ($Fe_2(SO_4)_3$) product can be used to remove phosphorus from municipal wastewater provided the wastewater has sufficient alkalinity to neutralize the excess sulphuric acid and has a neutral to alkaline pH. With low alkalinity wastewaters, lime must be added to neutralize the excess acid.

4. The cost of H_2SO_4 to recover Fe^{3+} was estimated to \$1.21/kg Fe^{3+} (56¢/lb Fe^{3+}). This was higher than the cost of commercial ferric chloride (53¢/kg Fe^{3+} (24¢/lb Fe^{3+})).

Authors: P.J.A. Fowlie and W.E. Stepko, Wastewater Technology Centre
35 pages; 12 figures; 7 tables; 12 references

Project Report: 72-3-4

RESEARCH REPORT NO. 75

Significance

The incineration of sewage sludge has increased in urban centres where land for the ultimate disposal of sewage sludge is restricted or is too distant to be used economically. Requirements for phosphorus removal from municipal wastewater treatment effluents have caused an increase in sludge volumes with considerably higher concentrations of phosphorus, its associated precipitant metals (e.g., Fe^{3+}, Al^{3+}, Ca^{2+}), and other coprecipitated metals which normally accumulate in the sludges. These elements survive the incineration process and appear in the incinerator ash. They will increase the weight of ash to be disposed of and may also cause long term environmental problems due to metal leaching from ash disposal sites.

These problems may possibly be alleviated by recovering the precipitant and recycling it within the treatment plant for phosphorus removal. Recovery costs may be partially offset by the lower quantity of fresh precipitant chemical that would be required.

Project Outline

During 1972, the Wastewater Technology Centre (WTC) of the Environmental Protection Service (EPS) initiated an experimental program aimed at developing and demonstrating technology for sludge incineration and precipitant recovery applicable to municipal wastewater treatment sludges. The objective of this program was twofold: (1) to investigate the recovery of lime and iron from chemical phosphorus removal sludges for the recycling of these chemicals in the phosphorus removal process, and (2) to evaluate multiple-hearth incineration of alum, iron and lime sludges.

As part of this research and development program, one of the first activities was to conduct an extensive review of the literature on sludge incineration and precipitant recovery processes. The information was published as a coded bibliography in Volume I.* Bench scale investigations to determine

*Volume I- Canada-Ontario Agreement Research Report No. 31

the feasibility of recovering and recycling iron from sludge incinerator ash are the subject of a separate publication - Volume II.*

This report (Volume III) summarized the findings of the laboratory scale investigations undertaken to supply basic information pertaining to the incineration characteristics of sludges from selected water pollution control plants in Ontario. The sludges studied were categorized as: alum, iron or lime sludge depending upon the chemical employed for phosphorus removal.

A subsequent report in this series will describe pilot scale studies designed to optimize multiple-hearth furnace operating parameters for an iron-rich sludge (Hamilton Water Pollution Control Plant (WPCP)) and to establish scale-up relationships between pilot and full scale multiple-hearth sludge incinerators.

Methodology

Samples of dewatered sludge were obtained from eight wastewater treatment plants in Ontario for laboratory scale experiments pertaining to sludge incineration. Selection of treatment plants was based on sludge type, treatment process, and the existence of sludge incineration facilities at three of these plants. Sludge types included raw primary, waste activated, and anaerobically digested mixed sludge. Four of the eight treatment plants were practicing phosphorus removal through chemical addition (alum, ferric chloride or lime).

Laboratory scale investigations consisted of determinations for total solids and volatile solids content, calorific values, tube furnace tests at temperatures over the range of 760°C (1 400°F) to 925°C (1 700°F), and thermogravimetric analyses over the temperature range from 200°C (390°F) to 925°C (1 700°F).

Conclusions

1. Sludge properties of special interest with respect to incineration are: moisture content, volatile solids content, amount and nature of fixed solids and calorific value. Reliable values for these sludge properties can be obtained in the laboratory through carefully conducted experiments.

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*Volume II- Canada-Ontario Agreement Research Report No. 74

2. The municipal wastewater sludges studied exhibited a broad range of calorific values depending upon the sludge type and pre-treatment process involved. In general, digested sludges have lower calorific values than raw primary or waste activated sludges, and chemical sludges have lower calorific values than do their non-chemical counterparts.

3. Addition of inorganic chemicals, such as lime and aluminum or iron salts, in the quantities normally used for phosphorus removal or sludge conditioning increases the concentration of inert material in the sludge mass and adversely affects the heat balance of the sludge combustion process.

4. The average calorific value for the eight sludges investigated was calculated to be 12 110 kJ/kg (5 210 BTU/lb) on a dry solids basis. Individual values spanned the range from 4 114 J/kg DS (1 770 BTU/lb DS), for a lime phosphorus removal sludge from a drying bed at the CFB Borden primary sewage treatment plant, to 16 570 kJ/kg (7 130 BTU/lb) of dry solids, for the heat treated sludge sample originating from the Mississauga Lakeview WPCP.

5. Calorific values calculated in this report using three different empirical equations generally compared favourably with each other. Except for the phosphorus removal lime sludge from CFB Borden, the estimated values fell within ±20% of the experimentally determined values.

6. Using data obtained in this study for chemical and non-chemical sludges, a linear mathematical relationship was established between sludge volatile solids content and the experimentally observed calorific values. The equation derived for the eight sludges investigated is:

$$C_v(\text{kJ/kg DS}) = 291(\text{VS}) - 1\,300$$

or:

$$C_v(\text{BTU/lb DS}) = 128(\text{VS}) - 632$$

7. Tube furnace investigations and thermogravimetric analyses indicated very little, if any, volatilization of "fixed sludge solids" at combustion temperatures ranging from 760°C (1 400°F) to 925°C (1 700°F). Combustion of organic matter in the sludge is complete at these temperatures and constant ash production can be expected.

8. Tube furnace tests can provide useful information on the extent of volatile solids reduction as a function of temperature, the temperature range suitable for incineration of a particular sludge, and can indicate the temperature at which fusion of ash and clinker formation begins. This experimental technique is, however, severely limited in the information it can provide on important incinerator operating and design parameters such as: loading rate, residence time, excess air requirements, equipment size and auxiliary fuel requirements.

Recommendations

1. In investigations pertaining to sludge incineration, a characterization of the sludge, both as to its type and its treatment history, should be undertaken as these parameters influence the combustion properties of the sludge.
2. If reliable data for calorific values of wastewater sludges are desired, they should be obtained experimentally with a bomb calorimeter rather than by calculation from existing empirical equations.
3. Pilot and/or full scale studies should be conducted to extend the tube furnace investigations described herein and to provide information on the optimum process parameters for incinerating sludges resulting from chemical wastewater treatment.

Authors: W.H. Schroeder and D.B. Cohen, Wastewater Technology Centre
38 pages; 5 figures; 9 tables; 51 references

Project
Report: 72-3-4

SLUDGE METAL SOLUBILITIES IN SOILS

M.D. Webber and G.M. Corneau
AGRICULTURE CANADA

Eight anaerobically digested Ontario sewage sludges, including two lime, four ferric chloride and two without P-removal chemicals were mixed with six soils and incubated in the laboratory under a variety of simulated field conditions. The sludges exhibited a wide range of metal contents and the soils a wide range of chemical and physical properties. Following incubation, the sludge-soil mixtures were extracted with 0.005M DTPA, 0.5N HOAc, 0.05M EDTA and 0.01M $CaCl_2$ to measure Cd, Zn, Cu, Ni, Pb, Co, Cr and Sn solubilities, and with acid ammonium oxalate, 1N $(NH_4)_2CO_3$ and 0.02M KCl to measure Mo solubility. In addition, columns of soils limed to pH 7 and treated with sludges were leached with 0.02M KCl to determine the potential for Mo movement.

Adding sludge increased the levels of extractable Cd, Zn, Cu, Ni, Pb and Mo in soils in relation to the amounts of metals added. The sludges contained small amounts of Co and caused no consistent changes in extractable Co, while Cr and Sn were not detected in any of the extracts. DTPA-extractable Zn, Ni, Pb and Co increased with increasing organic matter contents of the soils whereas DTPA- and HOAc-extractable Zn decreased with increasing clay contents.

Incubating sludge-soil mixtures under a variety of simulated field conditions indicated that the levels of extractable metals were largely independent of weather conditions likely to occur in Ontario. They were approximately the same following incubation at -15°C, 10°C, 25°C, and alternate -15°C and 25°C. Anaerobiosis generally reduced metal solubilities but is unlikely to occur widely under field conditions. Liming reduced the levels of DTPA-extractable Zn and Ni but not of Cu, Pb or Cd. Adding a large amount of newspaper to the sludge-soil mixtures caused little if any change in metal solubilities. Repeated applications of sludges containing large amounts of metals caused very high levels of extractable metals.

Leaching removed Mo from sludge treated soils and the loss was most rapid from the soil with the lowest clay and organic matter contents. No Cd was detected in the leachates.

CHEMICAL SEWAGE SLUDGE DISPOSAL ON LAND (LYSIMETER STUDIES)

VOLUME II

Wastewater Technology Centre

RESEARCH REPORT NO. 79

Significance

A recent survey of sludge disposal practices in Ontario indicated substantial increases in both sludge volumes and dry weight as a result of chemical additions to wastewater for phosphorus removal. The chemicals most commonly used for this purpose are alum, ferric chloride or lime.

Little information is available concerning the environmental impact of chemical sludges in either liquid (fluid) or dry forms when applied to a wide variety of agricultural soils producing many different crops. Of particular concern to public health authorities and regulatory agencies are the potentially deleterious effects on soils, groundwater, and plants of the numerous toxic substances such as heavy metals which are increasingly concentrated in wastewater sludges as effluent regulations become more stringent.

The long term risks of applying chemical sludges to farmland must be assessed.

Program Outline

To provide some of this information, a lysimeter project was initiated in October, 1972 by Environment Canada at the Wastewater Technology Centre, Burlington.

Two separate lysimeter experiments were designed to determine long term effects on soils, plants, and leachate of applying:

1. Fluid digested chemical sludges (alum, iron, and lime) to two medium textured soils growing orchard grass.
2. Air-dried digested chemical sludges to clay and sand, growing wheat crops.

The major objective of these ongoing studies is to determine the maximum sludge application rates which can be applied to various agricultural soils growing either forage or edible crops (wheat) without causing deleterious effects to:

- soil productivity (crop yield);
- plant quality (heavy metal toxicity); and
- groundwater quality (for drinking or irrigation water).

A separate report summarizes results of the fluid sludge lysimeter experiment to the end of 1974. Another report summarizes the results of the air-dried sludge lysimeter experiment to the end of 1975.

In this report the results of both the fluid sludge and air-dried sludge lysimeter experiments, to the end of 1976, are compared to data from:

- Ontario sludge disposal survey (1975).
- University of Guelph field and greenhouse experiments (1973 to 1975).
- Survey of plant metal uptakes from Ontario sludge farm sites (1976).
- Ontario Ministry of Agriculture and Food (OMAF) guidelines for sludge utilization on agricultural land.

Subsequent reports in this series will continue to update information on these ongoing studies.

Methodology

The first experiment, begun in 1972, was designed as a randomized block of 66 lysimeters with two soil types, three replications, and eleven fertility treatments consisting of three sludge types, three sludge rates and two controls (with and without NPK commercial fertilizer). The sludge consistency (fluid), soil types (medium texture), and agricultural crop (orchard grass), were chosen to enable subsequent comparison with the most common practice of sludge disposal to agricultural land in Ontario. A perennial grass crop was used for maximum potential nitrogen uptake. Sludge loading rates (kg TKN/ha) were chosen to closely approximate the crop soluble nitrogen requirement at the lowest rate, with the medium and high rates double and triple the low rate. Sludge types were chosen to include the three most common chemicals used for phosphorus removal (alum, iron and lime).

Fluid sludge was applied three times in 1973, four times in 1974, and five times in 1975 and 1976, each time at 100, 200, and 300 kg TKN/ha, resulting in cumulative loading by 1976 of 5 100 kg TKN/ha at the highest rate.

The second experiment, begun in 1973, was designed as a randomized block of 44 lysimeters, eleven fertility treatments replicated twice on two different soils. Air-dried (∿5% moisture) sludge rather than fluid sludge was used to assess the provisional OMAF guidelines (1976) which are based on a soluble NH_4-N to metals ratio. The crop selected was wheat (spring and fall wheat) to enable a comparison of metals uptake in both the grain and leafy portions of the plant. Sludge loadings

were based on Chumbley's (1971) zinc equivalent recommendation of no more than 250 mg/kg zinc equivalent metal addition to soil to prevent toxicity to plants. Actual sludge loadings at the end of the first year were 6, 12, and 18 times the maximum zinc equivalent loading recommended by Chumbley.

Two widely divergent soils were chosen for this experiment, namely a sand soil having zero clay and only 3.0% silt in the "A" horizon, and a clay type soil with 33% clay and 59% silt. Sludge was applied in 1974, but not in 1975 or during the 1976 growing season.

Crop yields were determined and the plant tissue was analyzed for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), manganese (Mn), iron (Fe), aluminum (Al), zinc (Zn), copper (Cu), nickel (Ni), cadmium (Cd), chromium (Cr), and lead (Pb).

Leachate was collected periodically to represent different periods of the year. Leachate quality was monitored for pH, conductivity and chemically analyzed for nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), nitrite nitrogen (NO_2-N), total Kjeldahl nitrogen (TKN), chloride (Cl), sulphate (SO_4), total carbon (TC), total organic carbon (TOC) as well as P, K, Ca, Mg, Na, Fe, Al, Mn, Zn, Cu, Ni, Cr, Cd, and Pb.

Initial soil characteristics and sludge quality were also monitored for nutrients and metals to permit mass balance determination.

Samples of sludge, soil and leachate were collected periodically for microbial analysis. Static bioassay toxicity tests using Daphnia were conducted during 1976.

Conclusions

1. Sludge constituent loadings (maximum rate) to lysimeter soils were 10 to 50 times the 1975 average annual loading to sludge farms in Ontario.
2. The OMAF sludge criterion relating the minimum acceptable ratio of soluble, NH_4-N/heavy metals would allow use of fluid but not air-dried sludges. As nitrogen to metal ratios were higher, and metal concentrations lower in plant tissue receiving air-dried than fluid sludges, this criterion should be reconsidered for dry sludge applied to farmland.
3. At least 200% of NPK nitrogen rates must be applied as fluid sludge to obtain orchard grass yields equivalent to NPK treatment. The residual beneficial effect of cumulative sludge applications is evident as 89% of sludge treatment yields exceeded NPK in 1976 (loamy sand) compared to only 22% in 1973. Air-dried

sludge wheat yields (sand) exceeded NPK yields in 78% of sludge treatments in 1974, but declined to 0% in 1976. Wheat grain yields (1976) declined on sandy soil to 38% of NPK yields but increased to 103% of NPK from clay soil.

4. The heavy metals Cd, Cr, Cu, Ni, Pb, and Zn did not exceed suggested maximum "tolerance" or "toxic" concentrations in orchard grass or wheat crops (mean of all sludges 1973 to 1976). Metal concentrations in wheat grain were generally lower than in straw.

5. Only Zn was taken up by orchard grass or wheat crops in amounts exceeding the OMAF referenced maximum uptake of 0.3 kg/ha/yr. Zinc and Cu uptake by orchard grass at the highest sludge rate was twice the NPK uptake rate. Nickel, Cr, and Cd uptakes from sludges did not exceed NPK uptakes per equivalent dry matter yield. The uptake of metals in all crops receiving alum, iron or lime sludges reflect TKN uptake rather than sludge metal loading ratios.

6. Leachate volume losses from orchard grass soils varied inversely with crop yield and sludge application rate for each soil type. Leachate losses from air-dried sludge-wheat soils did not vary significantly with sludge loading rate.

7. Leachate maximum concentrations of Cd, Cr, Cu, Ni, Pb, and Zn did not exceed drinking water standards. Metals concentrations (mean of all sludges) were similar to NPK control. No increasing concentration trend for any metal monitored was observed during 1973 to 1976.

8. Nitrogen as NH_4-N rarely exceeded the drinking water MPC of 0.5 mg/L. The nitrate (NO_3-N) MPC of 10.0 mg/L was not exceeded during 1974 or 1975 (orchard grass) but increased during 1976 where alum and iron sludges (high rate) were applied to both soils. NO_3-N in leachate from lime sludge never exceeded 10.0 mg/L and was significantly lower than NO_3-N from alum or iron sludge applications. NO_3-N in leachate from air-dried sludge applications remained unacceptably high during 1974 to 1976. Control NO_3-N concentrations frequently exceeded 10.0 mg/L.

9. Soluble P in leachate exceeded 1.0 mg/L only from the high rate alum sludge treatment (loamy sand). Soluble P from all other sludge treatments to all soils generally met the drinking water MPC of 0.1 mg/L.

10. TOC in leachate from both experiments increased to >50 mg/L in 1976 at the highest sludge loading rates. Static bioassay toxicity tests using Daphnia showed no toxicity in leachate samples having high TOC values.

11. Limits related to water quality criteria are required for constituents of concern in leachate from sludge amended soils. Based on data from these lysimeter

experiments, nitrate is the constituent of major concern in leachate, particularly when air-dried sludge is applied to a low nitrogen uptake crop. If leachate quality from normal agronomic (NPK) treatment is used as a standard of comparison, application of sludges at rates similar to NPK should not adversely affect groundwater quality. If drinking water criteria are adopted for leachate quality, commercial NPK application rates may also have to be regulated.

12. Recovery of NO_3-N in leachate as a percent of nitrogen applied to soil averaged 3% from fluid sludge and 33% from air-dried sludge at the highest rate. Heavy metal recoveries did not exceed 1% with the exception of cadmium and nickel. Nickel recovery from fluid sludge averaged 6.2% compared to 1.8% from air-dried sludge.
13. Brome grass crop yield trends from University of Guelph field experiments were similar to lysimeter orchard grass yield response to sludge treatments.
14. Plant tissue heavy metal concentration trends (highest rates of alum, iron, and lime sludges) were generally similar for both lysimeter and field experiments. Cadmium did not increase in either field, greenhouse or lysimeter experiments using similar sludge sources. Copper increased somewhat in both lysimeter and field experiments, but did not exceed the suggested toxic concentration (20.0 ug/g). Rye grass grown in the greenhouse showed some yield depression attributed to Cu toxicity. Nickel did not exceed the suggested tolerance concentration of 3.0 ug/g in either lysimeter or field experiments. Even concentrations of Ni in excess of 40 ug/g in rye grass (greenhouse) did not show any apparent yield depression effect. Zinc increased slightly in field experiments but not in lysimeter experiments. Rye grass Zn concentrations above the suggested toxic level of 200 ug/g did not show any yield depression effect. Lead concentrations did not increase in either lysimeter, field or greenhouse experiments. High Pb values in lysimeter experiment crops are attributed to aerial contamination.
15. Heavy metal concentration trends in plant tissue from the lysimeter experiments were compared with metal concentrations in crops from selected sludge farms and adjacent non-sludge control sites in Ontario. The sludge farms were selected on the basis of high sludge metals loadings over extended periods of time. The constituents analyzed included As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Zn, and PCB's. Although many of the heavy metals exceeded the OMAF maximum recommended content in soils, concentrations in plant tissue from sludged sites were generally not significantly greater than concentrations of these metals in plant tissue from control sites. The only exception was Mo, with one sludged site exhibiting

a potentially toxic concentration of Molybdenum in corn stover (24 ug/g).

16. More information is required concerning cumulative uptake of metals from a wide variety of agricultural crops, receiving sludge in either fluid or dry form. More information concerning the tendency of a particular crop to remove a particular "constituent of concern" from sludge amended soil with a high recovery efficiency could allow for increasing refinement in sludge application guidelines as currently proposed.
17. If nitrate pollution of groundwater as a result of sludge application to soil becomes a major factor limiting sludge application rates, similar restrictions in application of commercial NPK fertilizers might be anticipated. Background information concerning the seasonal variability of NO_3-N concentrations in groundwater where no fertilizer is applied at all would be of benefit in evaluating the impact of sludge loadings on groundwater quality.
18. In view of the non-lethal toxicity results obtained to date from leachate samples having high TOC values, carbon chloroform extract (CCE) tests will, in future, be compared to TOC results to provide a more sensitive indication of potentially deleterious organic substances.
19. Lime sludge application even at the highest rate (unlike alum and iron sludges) did not result in unacceptable NO_3-N leachate levels in either soil during four years of monitoring. Further research is required to determine whether this differential nitrate formation is due to inhibition of soil nitrifying bacteria or accelerated gaseous nitrogen losses as NH_3 or N_2.

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NITRIFICATION-DENITRIFICATION OF WASTEWATER USING A SINGLE-SLUDGE SYSTEM

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Full-scale nitrification-denitrification of wastewater was conducted at the Newmarket, Ontario, Water Pollution Control Plant (WPCP), where primary stage lime treatment for phosphorus removal was being applied. The secondary treatment section was divided into two separate units, one for nitrification and the other for single-sludge nitrification-denitrification.

For nine months, fall to spring, the units were evaluated under ambient environmental conditions using, for the most part, on-site equipment. The object of this study was to see what degree of nitrification-denitrification could be maintained within a system with lime treatment. Experiments involved denitrification mixed liquor thickening, methanol dosing and supplementary iron salt addition for phosphorus removal.

Constant high (above 200 ml/g) sludge volume index (SVI) was experienced in both the nitrification and combined nitrification-denitrification units at Newmarket. This was thought to be caused by lime addition to the primary stage. Full nitrogen conversion and removal were disrupted by sludge chlorination for SVI control. Some limitations of the conventional facility were also found to affect nitrogen removal. Supplemental addition of ferrous sulphate, late in the program, to the aeration basin improved phosphorus removal and decreased SVI.

Subsequent pilot plant studies were carried out at Brampton and Kleinburg. In these a split-return mode of operation was evaluated under more controlled conditions. The requirements for methanol as a carbon source, process solids distribution, and post-aeration were evaluated for nitrification-denitrification under liquid temperatures ranging from 10 to 25°C.

More encouraging results were attained with the pilot unit. Denitrification solids thickening and thus improved nitrate removal was observed. Post-aeration proved necessary to maintain low effluent suspended solids, but did contribute dissolved oxygen to the denitrification tank contents.

Land application of Ontario sewage sludges will increase the solubilities of many heavy metals in soils and uncontrolled application of sludges containing large amounts of these metals will cause excessive increases. High metal solubilities in soils are likely to cause crop and animal toxicities; however, further work is required to define the critical levels. Molybdenum leached slowly from soils adjusted to pH 7 and high levels of that metal are not expected to persist in agricultural soils.